

PDF Uncertainties at Hadron Colliders



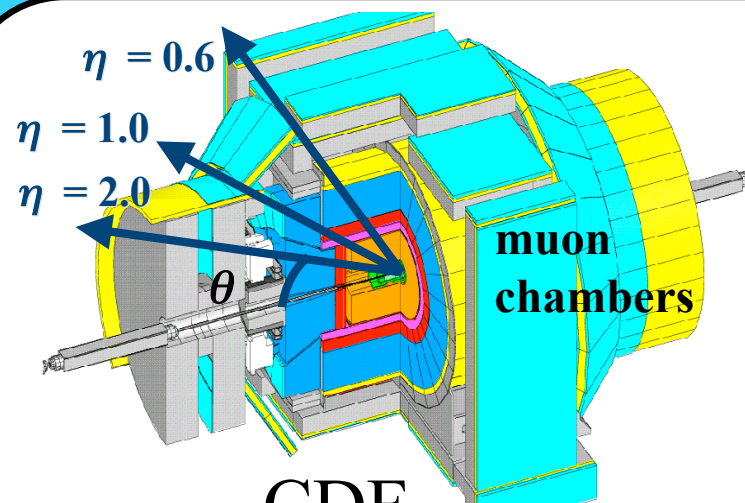
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for the CDF and D0 Collaborations
Diffraction 2006, Milos



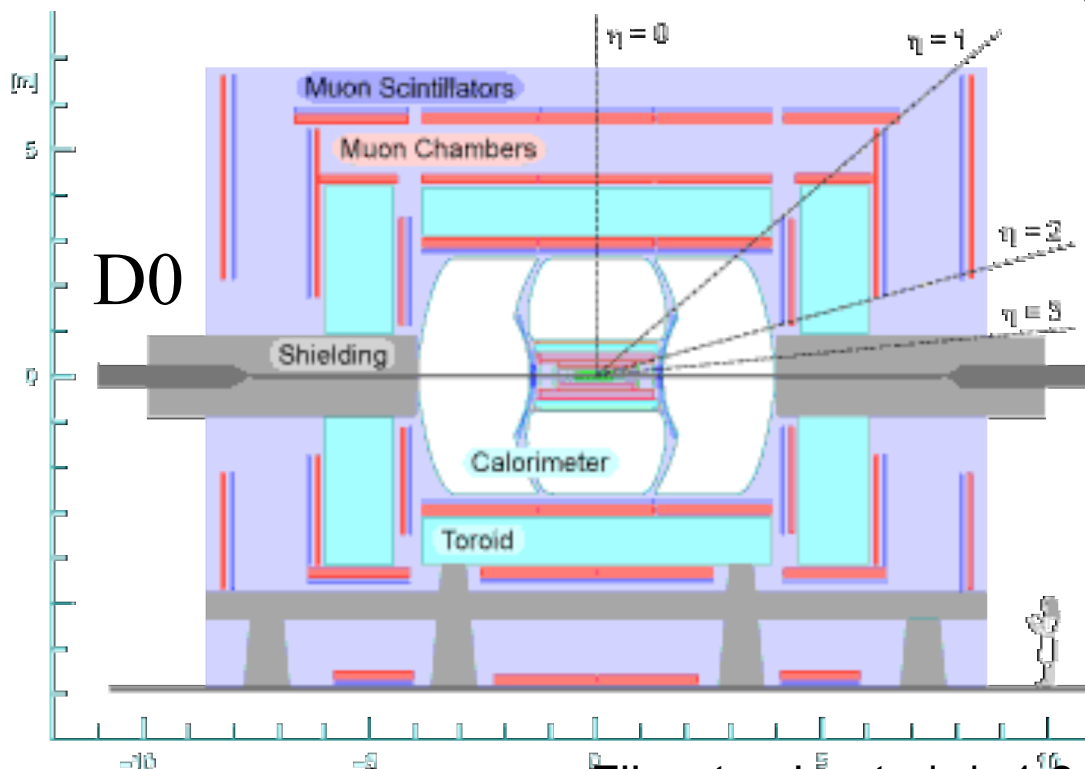
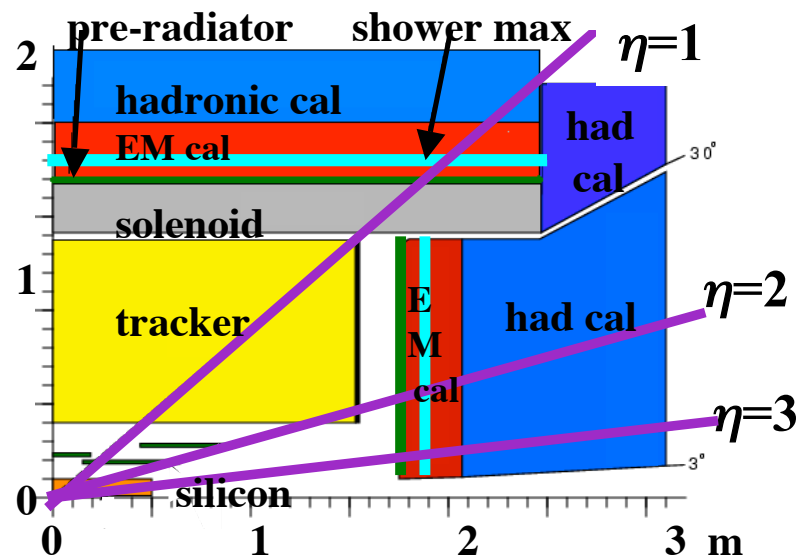
- ◆ Places where PDF uncertainties appear
- ◆ PDF-constraining measurements at the Tevatron



CDF and D0



CDF



D0

Fibre tracker to $|\eta| < 1.8$
Calorimeter to $|\eta| < 4$
Muon system to $|\eta| < 2$

Drift chamber to $|\eta| < 1$
Further tracking from Si
Calorimeter to $|\eta| < 3$
Muon system to $|\eta| < 1.5$

Quantifying PDF uncertainties

PDFs are parameterised fits to DIS/fixed target DY/Tevatron data

$$xf_a(x, Q_0) = A_0 x^{A_1} \cdot (1-x)^{A_2} \cdot e^{A_3 x} \cdot (1+A_4 x)^{A_5} \quad (\text{CTEQ})$$

where a are combinations of $u, d, g, \bar{u}, \bar{d}$

\Rightarrow 30 total parameters of which 10 fixed

Parameters determined at low scale $Q_0=1.3\text{GeV}$ and evolved

Eigenvectors formed in A_i space (20 for CTEQ, 15 for MRST)

‘Error’ PDF sets provided for each eigenvector at $\Delta\chi^2=100$ (CTEQ)
or 50(MRST) from best fit.

PDF uncertainties in W/Z

$$\sigma \cdot \text{Br}(W \rightarrow \ell \nu) = (2777 \pm 10_{\text{stat}} \pm 52_{\text{sys}} \pm 167_{\text{lum}}) \text{ pb} \quad (\text{CDF, } 72/\text{pb})$$

$$\sigma \cdot \text{Br}(Z/\gamma^* \rightarrow \ell \ell) = (254.3 \pm 3.3_{\text{stat}} \pm 4.3_{\text{sys}} \pm 15.3_{\text{lum}}) \text{ pb} \quad (\text{CDF, } 72/\text{pb})$$

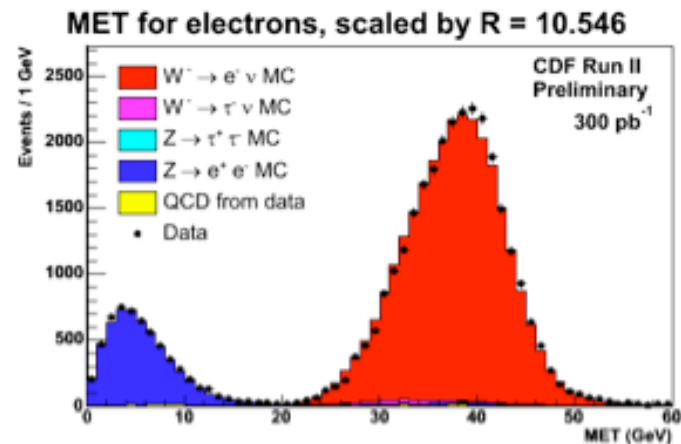
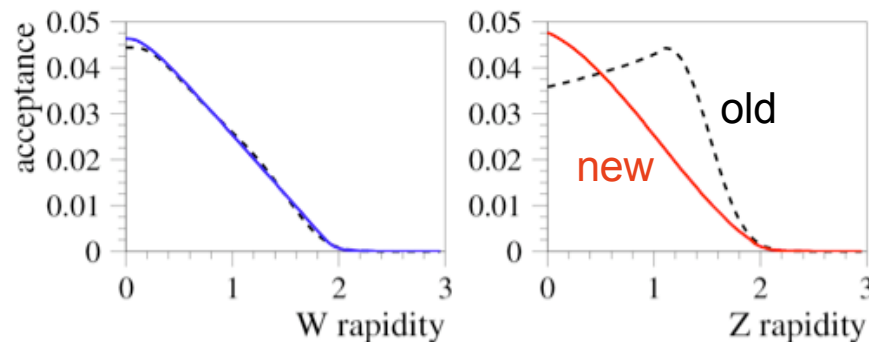
Cross-section systematic uncertainties **< 2%** of which PDF uncert. **~1%**

Luminosity uncertainty cancels entirely in ratio $R = \sigma_W / \sigma_Z$, but PDF does not

$$R = 10.84 \pm 0.15_{\text{stat}} \pm 0.14_{\text{sys}} \longrightarrow \Gamma(W) = 1092 \pm 42 \text{ MeV}$$

~0.6% from PDFs

Can design measurements to minimise PDF uncert.,
eg use same selection for W,Z ; extract R from E_T fit
reduces PDF uncertainty to **0.3%**



PDF uncertainties in $\sigma_{t\bar{t}}$, m_W

Top pair production

theoretical calculation $\sigma(p\bar{p} \rightarrow t\bar{t}) = 6.7^{+0.7}_{-0.9}$ pb

principal contribution is PDF uncertainty ($\sim 10\%$)

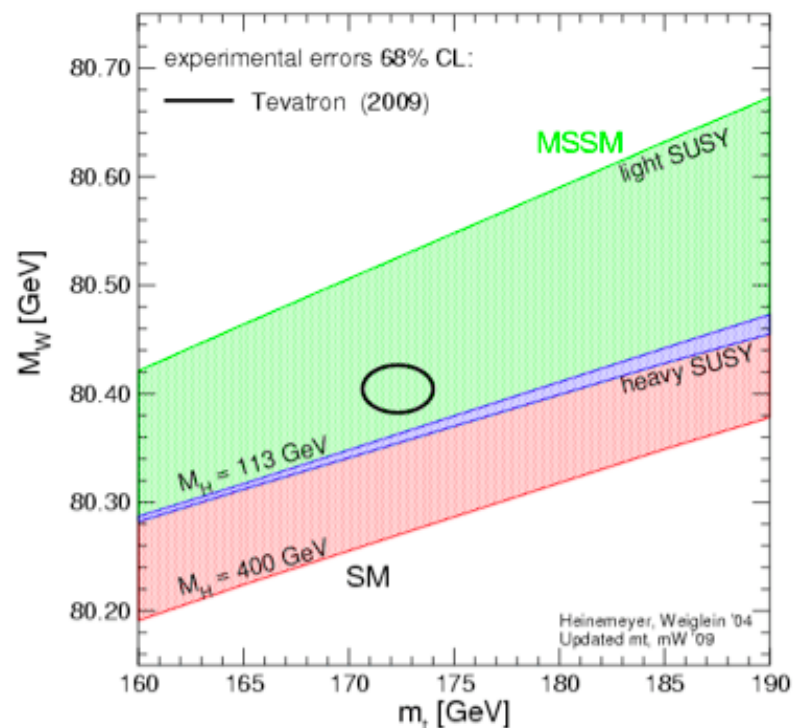
combined CDF measurement, 760/pb: $(7.3 \pm 0.5_{\text{stat}} \pm 0.6_{\text{sys}} \pm 0.4_{\text{lum}})$ pb

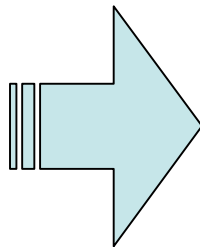
W mass

CDF preliminary, for 200/pb data

Systematic Uncert.	Electrons	Muons	
lepton scale & resn	70	30	roughly scale w/ luminosity
recoil scale & resn	50	50	
backgrounds	20	20	
QED	15	20	
W p_T model	15	15	
PDFs	15	15	

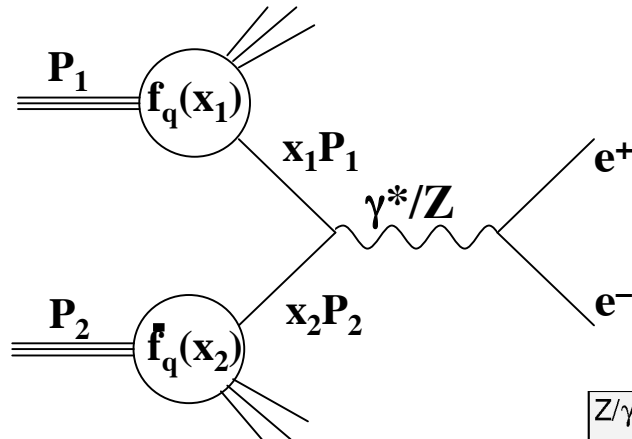
Total uncertainty: 76 MeV
(expected in 2/fb: 40 MeV)





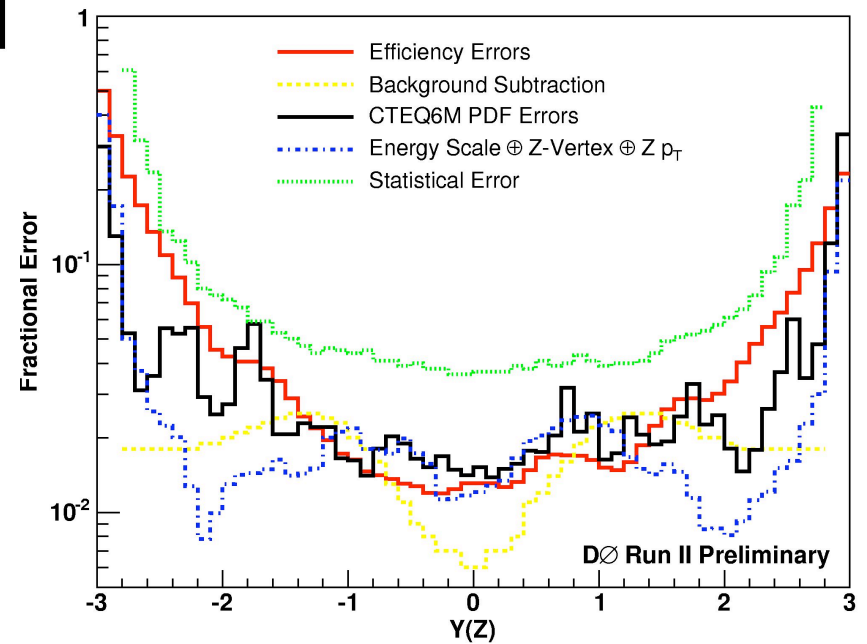
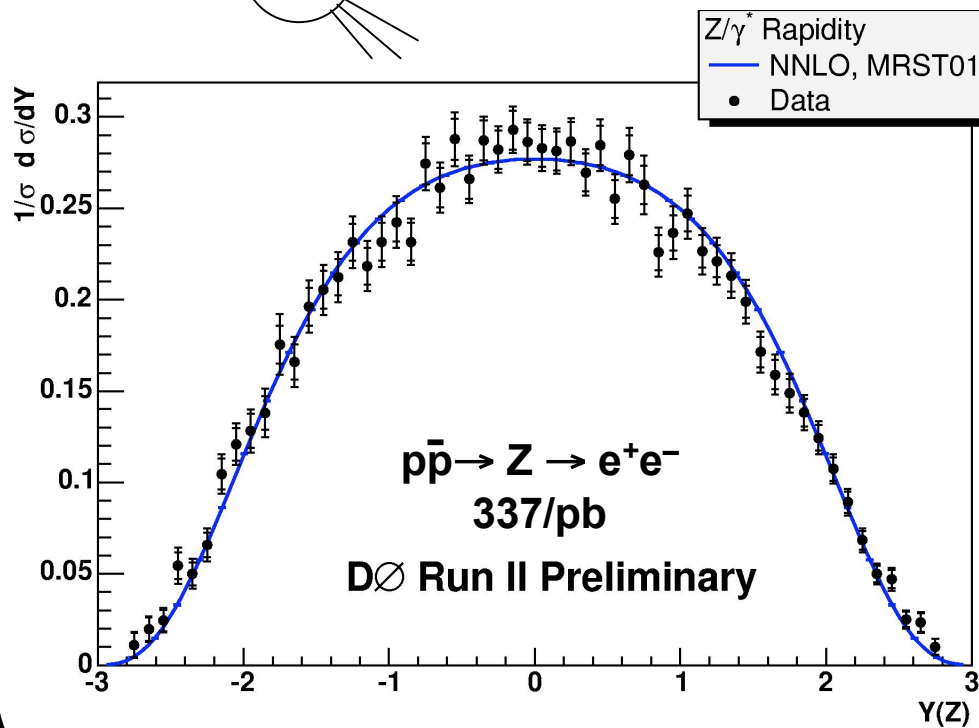
construct precision measurements
to be interpreted as PDF constraints

Z rapidity

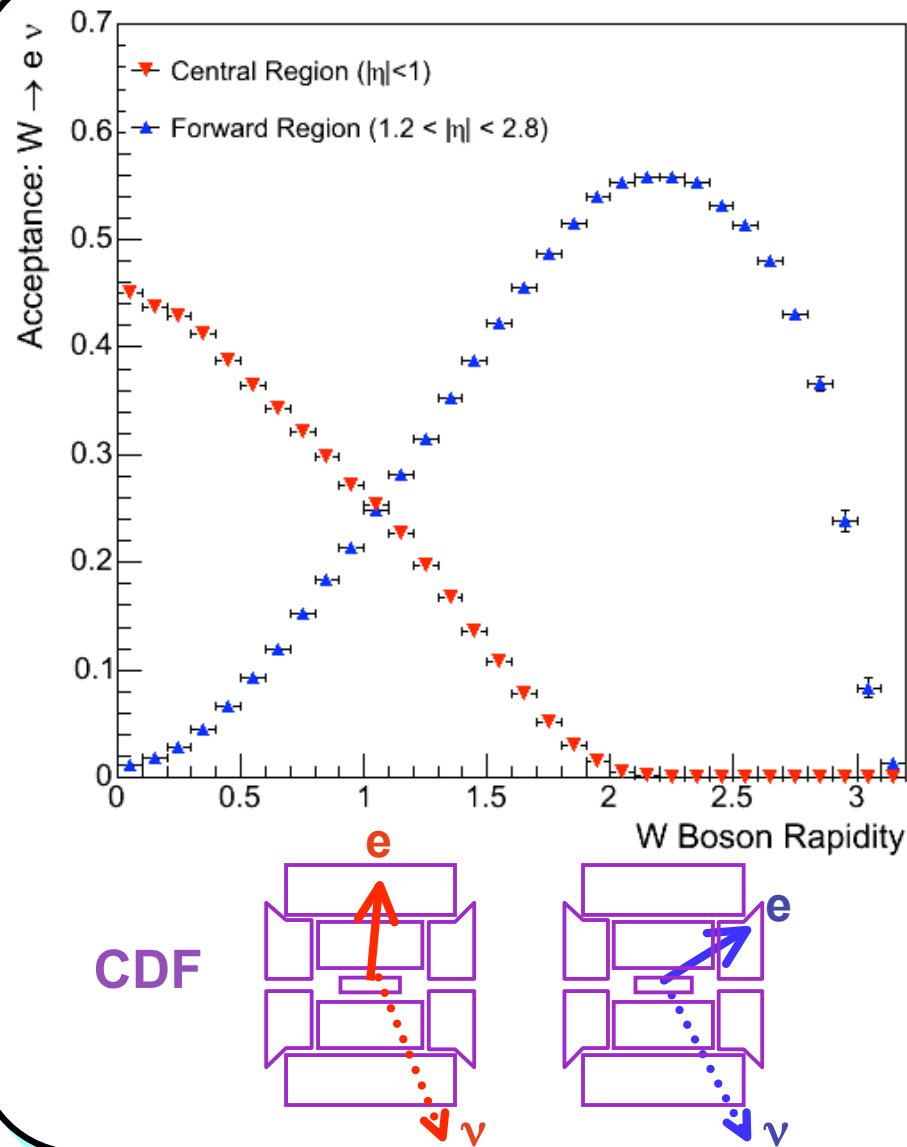


Z production: rapidity $y = \frac{1}{2} \ln \frac{E + p_z}{E - p_z}$

closely related to parton x : $x_{1,2} = \frac{m}{\sqrt{s}} e^{\pm y}$ (LO)

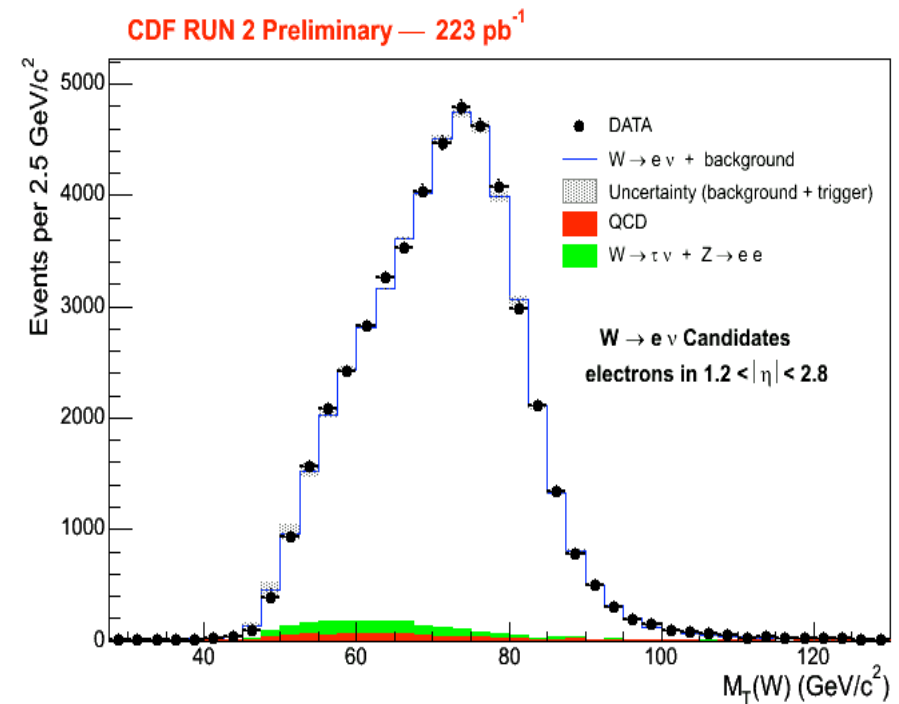


Forward W



Acceptance for forward W
cross-section complementary to
central W measurement in W rapidity

Measurement relies on Si-only tracking



Forward W

Central electron result: $\sigma_W = (2771 \pm 14_{\text{stat}} \pm 62_{\text{sys}} \pm 166_{\text{lum}}) \text{ pb}$

Forward electron result: $\sigma_W = (2796 \pm 13_{\text{stat}} \pm 95_{\text{sys}} \pm 162_{\text{lum}}) \text{ pb}$

Define visible cross-section $\sigma_{\text{vis}} = \sigma_{\text{tot}} \times A$

Ratio of σ_{vis} in central/forward regions sensitive to PDF distributions

$$R_{\text{exp}} = \sigma_{\text{vis}}^{\text{cent}} / \sigma_{\text{vis}}^{\text{forw}} = 0.925 \pm 0.033$$

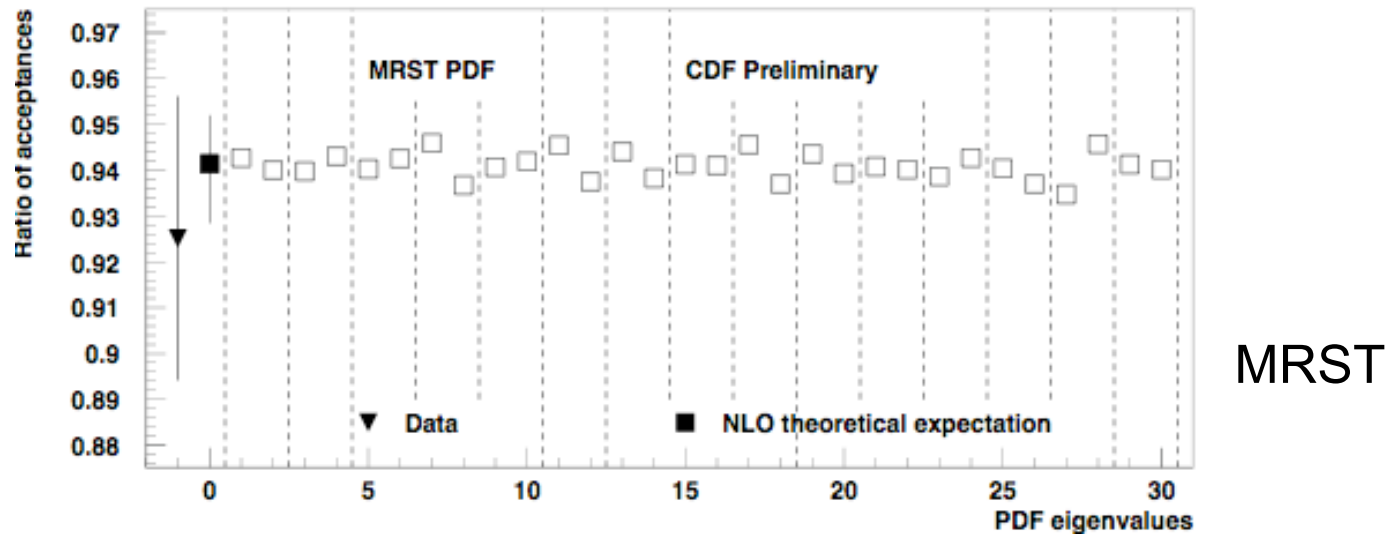
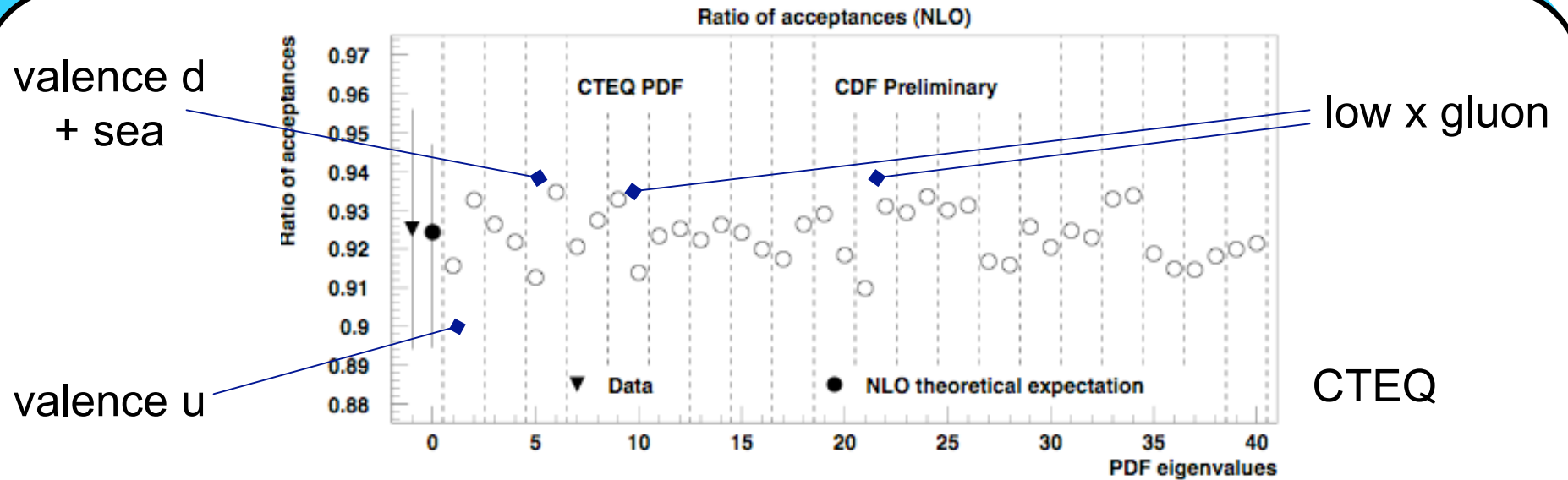
$$R_{\text{th}} = A_{\text{vis}}^{\text{cent}} / A_{\text{vis}}^{\text{forw}} = 0.924 \pm 0.037 \text{ (CTEQ 6.1)}$$

$$= 0.941 \pm 0.012 \text{ (MRST01E)}$$

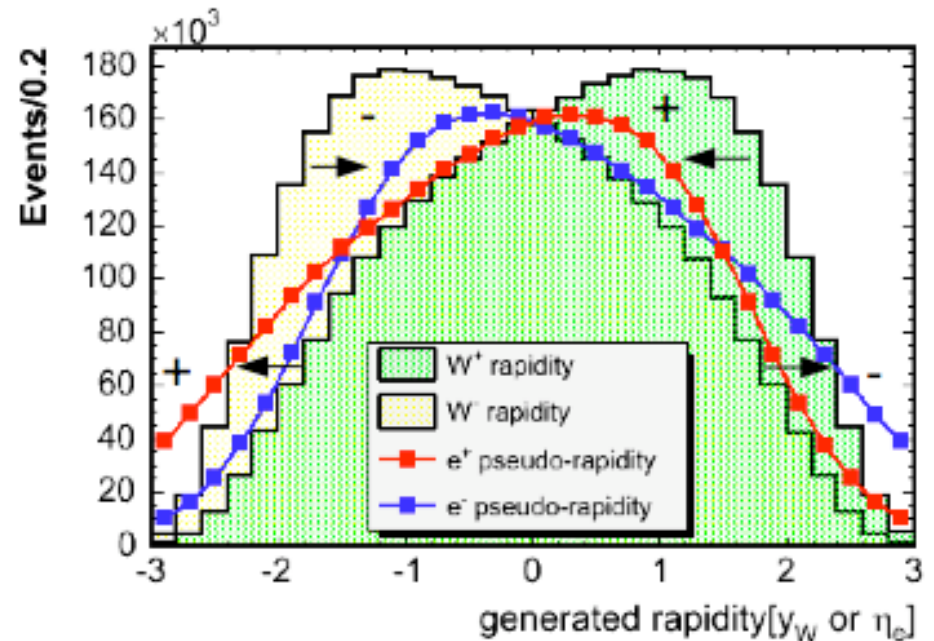
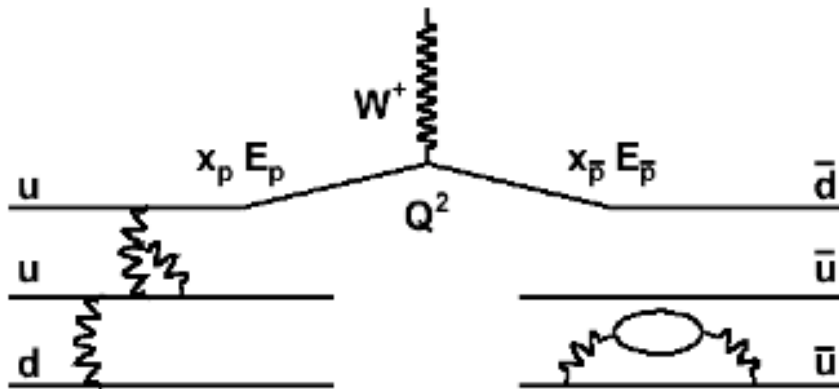
Uncertainties on R_{exp} :

electron identification	$\pm 2.5\%$
track reconstruction	$\pm 1.1\%$
luminosity	$\pm 1\%$
backgrounds	$\pm 1\%$

Forward W



W charge asymmetry



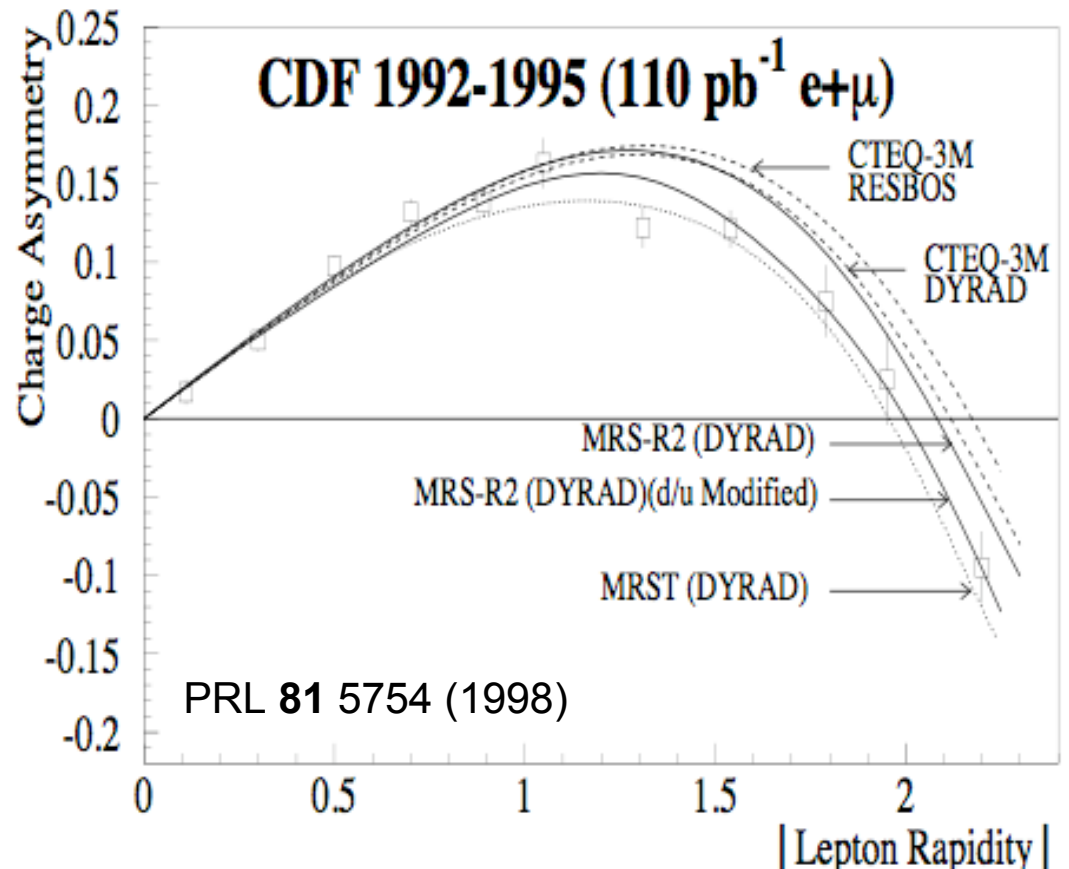
$$A_W(y) \equiv \frac{d\sigma(W^+)/dy - d\sigma(W^-)/dy}{d\sigma(W^+)/dy + d\sigma(W^-)/dy}$$

$$A_\ell(\eta) \equiv \frac{d\sigma(\ell^+)/d\eta - d\sigma(\ell^-)/d\eta}{d\sigma(\ell^+)/d\eta + d\sigma(\ell^-)/d\eta} = A(y_W) \otimes (V-A) \sim \frac{d(x)}{u(x)}$$

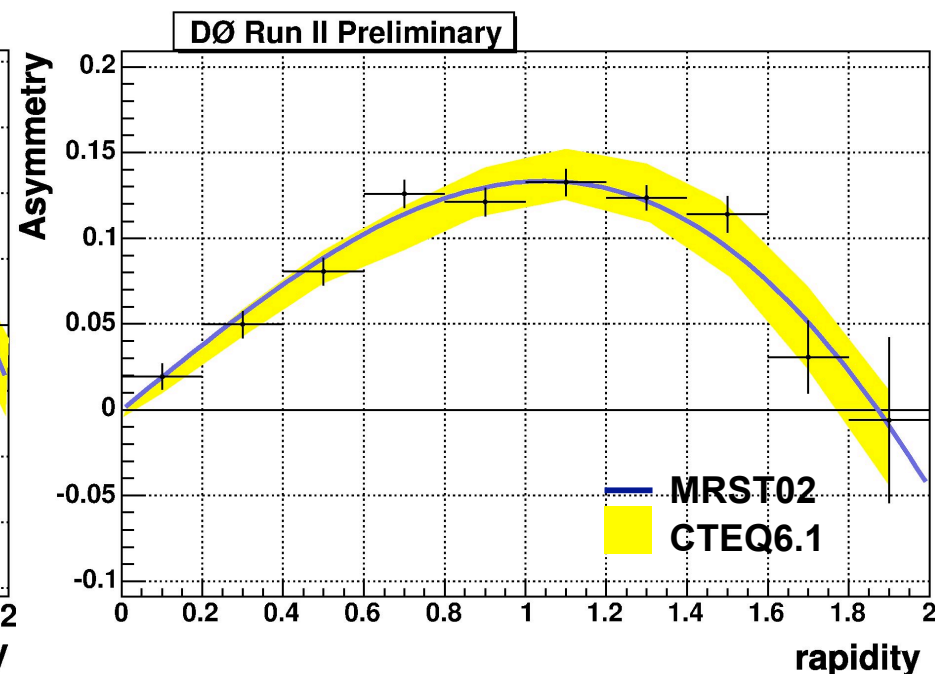
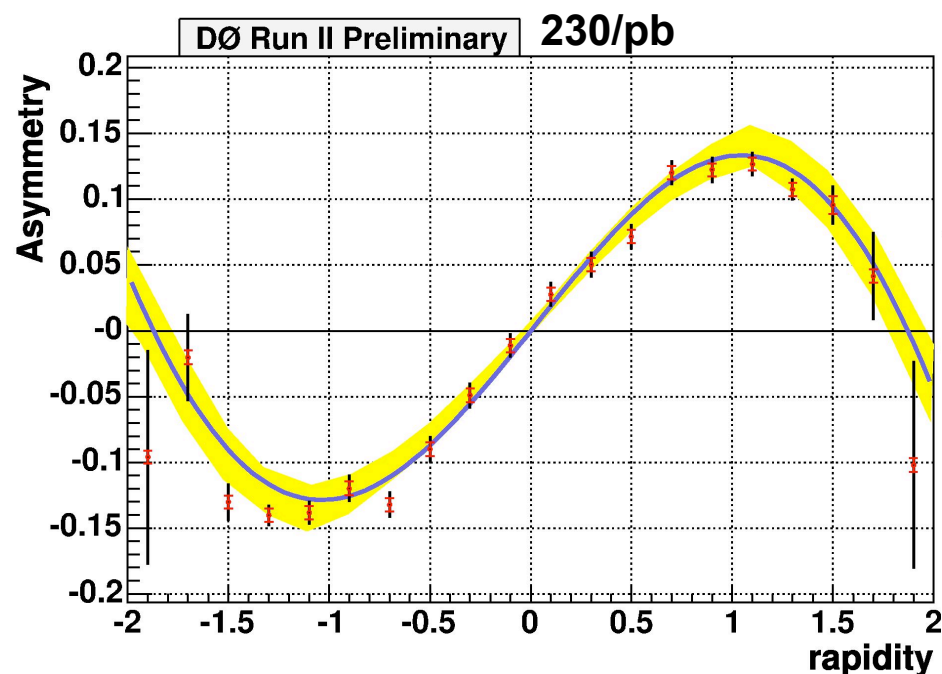
W charge asymmetry

DIS $\propto q^2$ so u is well measured

Run 1 measurement resulted in d quark increased by 30% at $Q^2=(20\text{GeV})^2$

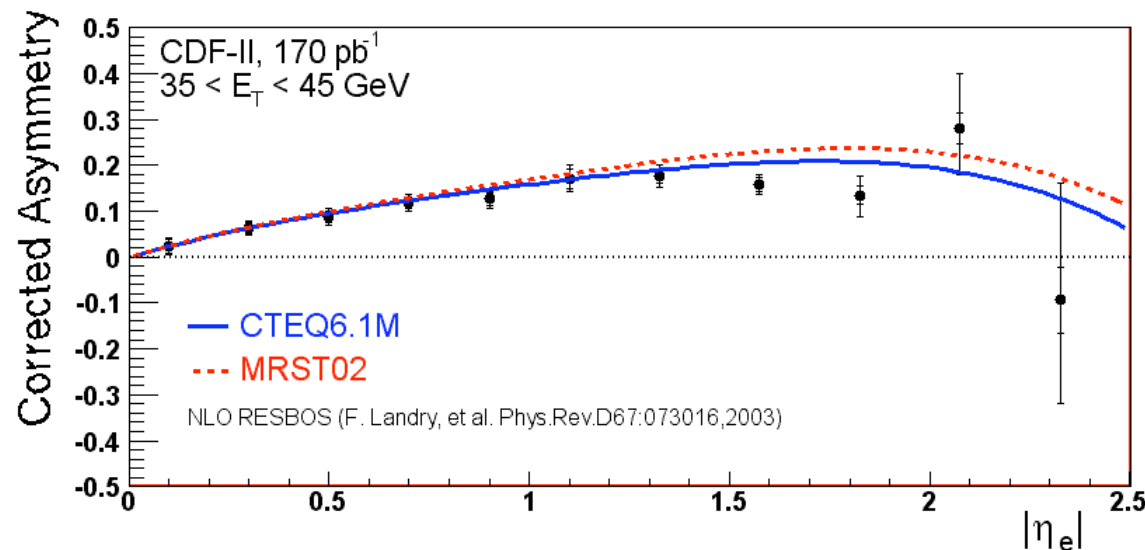
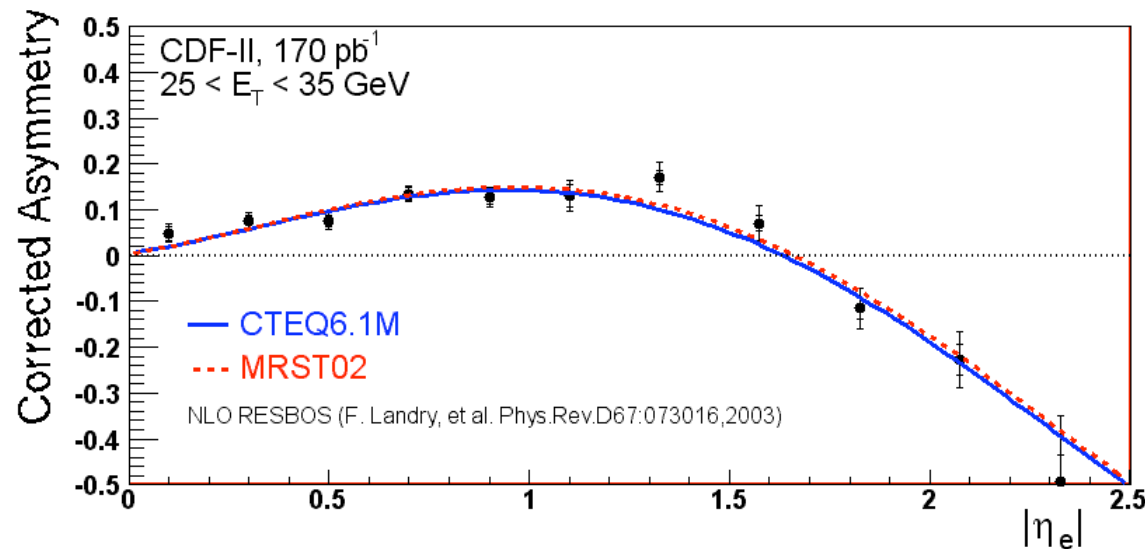


W charge asym. – D0



muon channel, $p_T > 20 \text{ GeV}/c$, $E_T > 20 \text{ GeV}$, $M_T > 40 \text{ GeV}/c^2$
isolated track with hits in fibre tracker and silicon
main systematic uncertainty hadronic energy scale (for E_T)
sensitive to d/u for $0.005 < x < 0.3$

W charge asym. – CDF



measurement relies on
calorimeter-seeded
silicon tracking

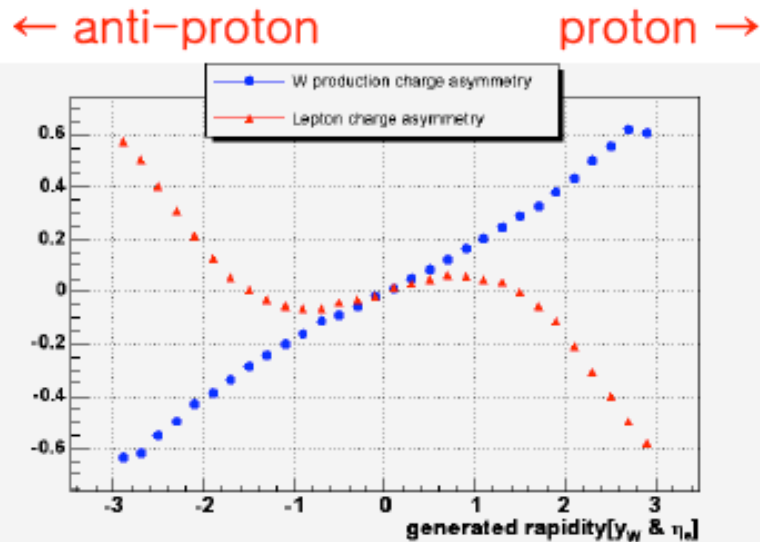
experimental challenges:
alignment
charge misidentification

unknown neutrino p_z
is a smaller effect for
higher E_T electrons

measurement divided
into two E_T regions

for given η_e , E_T regions
probe different y_W and
therefore different x

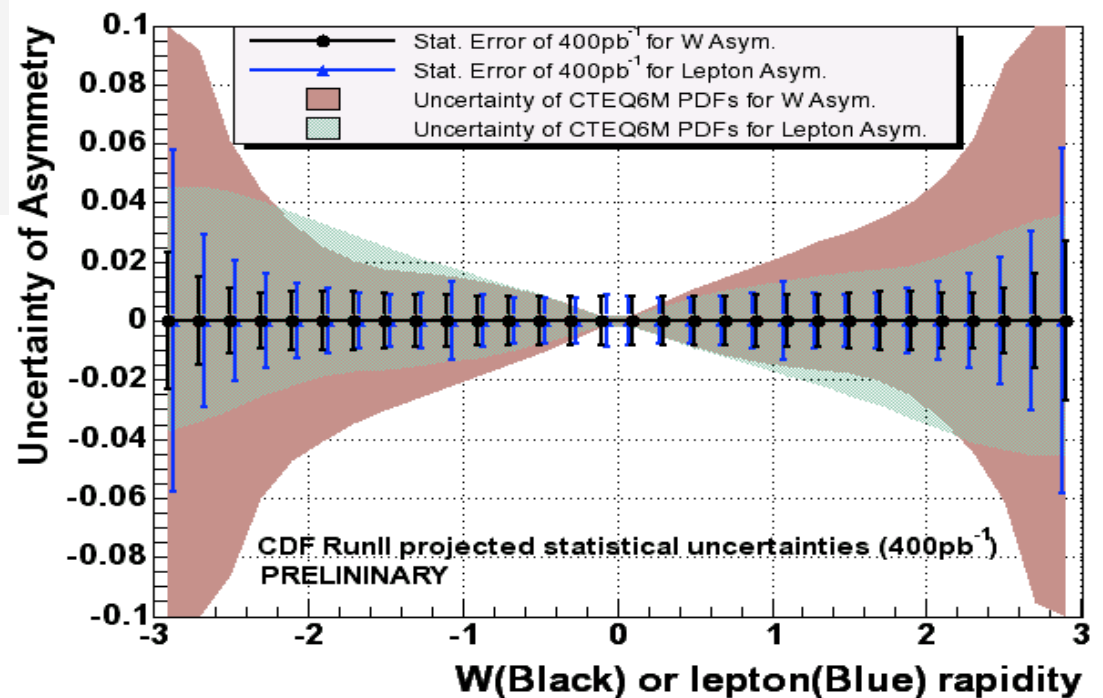
W charge asym. – CDF in progress



$d\sigma/dy$ is an input; iterate to remove dependence.

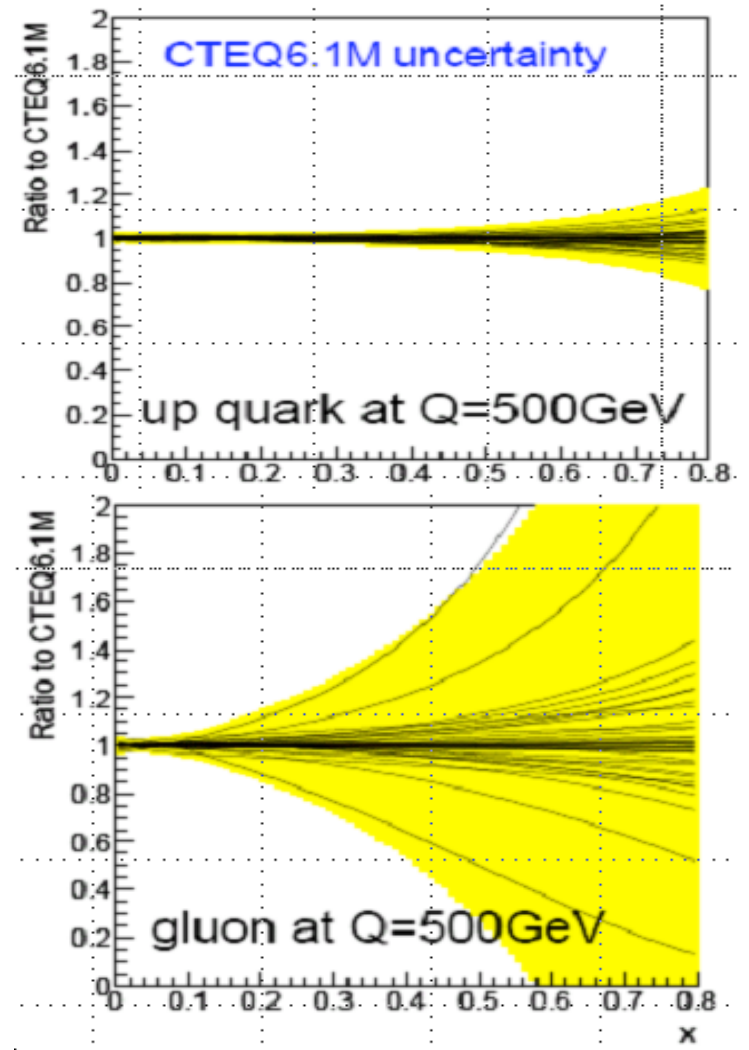
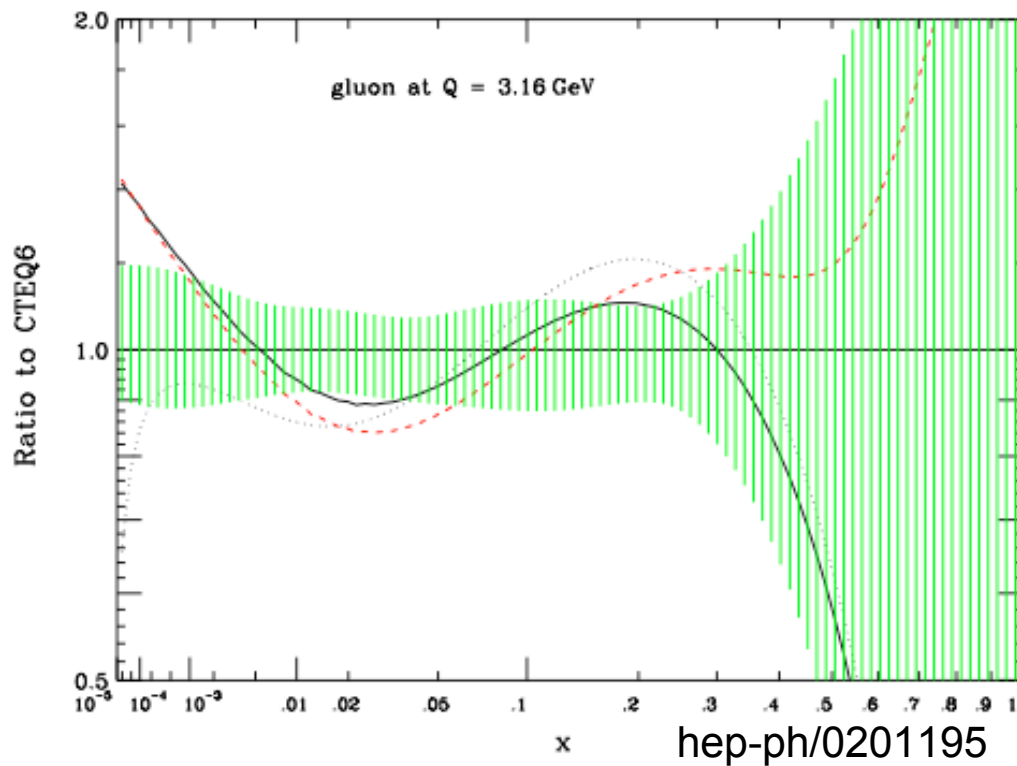
Studies suggest improved sensitivity.

We would like to probe the W rapidity directly
 M_W constraint → two kinematic solutions for p_z of ν .
 Ambiguity can be resolved statistically from known centre-of-mass θ^* distribution for V-A decay
 → weight solutions

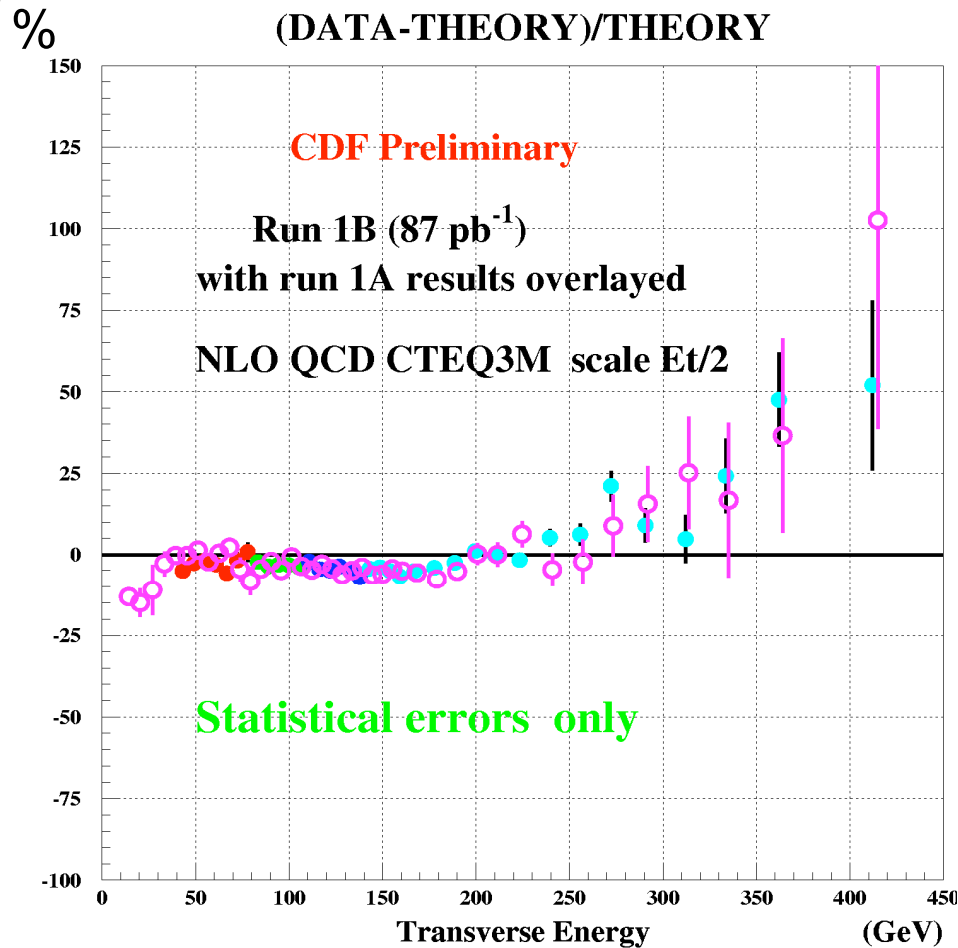


High- x gluon

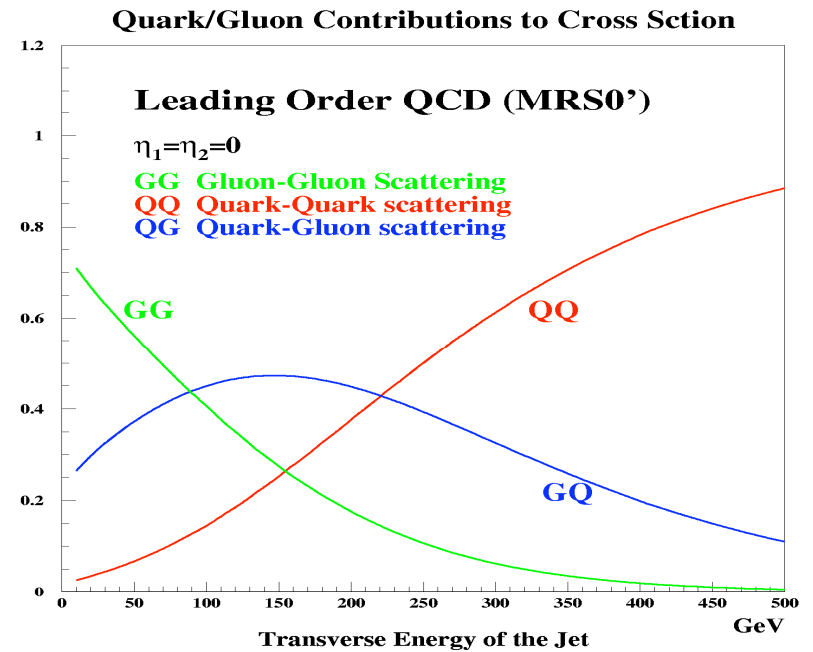
– the most uncertain PDF



Run 1 Inclusive Jets

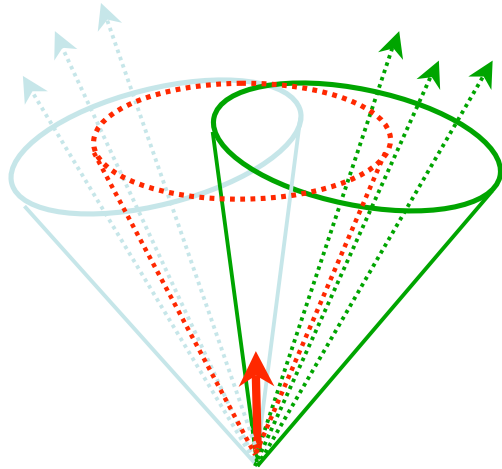


PDF uncertainty was underestimated
– data was in fact consistent with SM



Jet Algorithms

Run 2 midpoint algorithm

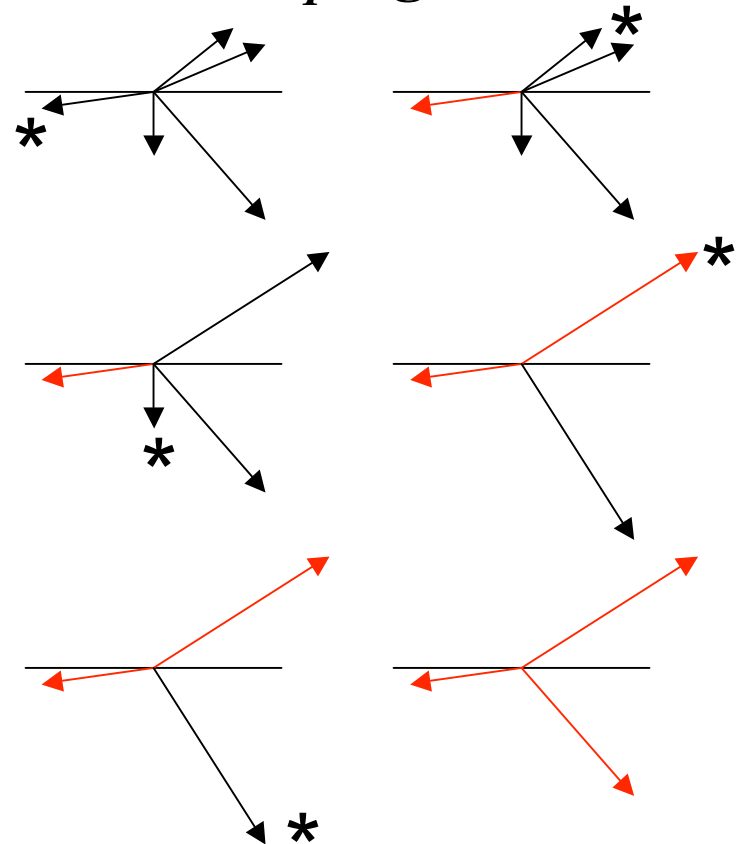


Based on cone in (η, ϕ)

Extra seed placed at midpoint (η, ϕ) of pairs of proto-jets separated by less than $2R$ for improved IR safety.

Merging/splitting of overlapping jets

Run 2 k_T algorithm



Proto-jets combined according to separation in transverse momentum k_T , starting from smallest k_T

Inclusive Jets

Events collected with single-jet triggers

Interactions required to be in centre of detector (D0 $|z| < 50\text{cm}$, CDF $|z| < 60\text{cm}$)

Missing E_T required to be low (remove cosmic/beam backgrounds)

Jets clustered

Effects of multiple $p\bar{p}$ interactions removed

D0 estimate from “offset energies” from zero-bias events

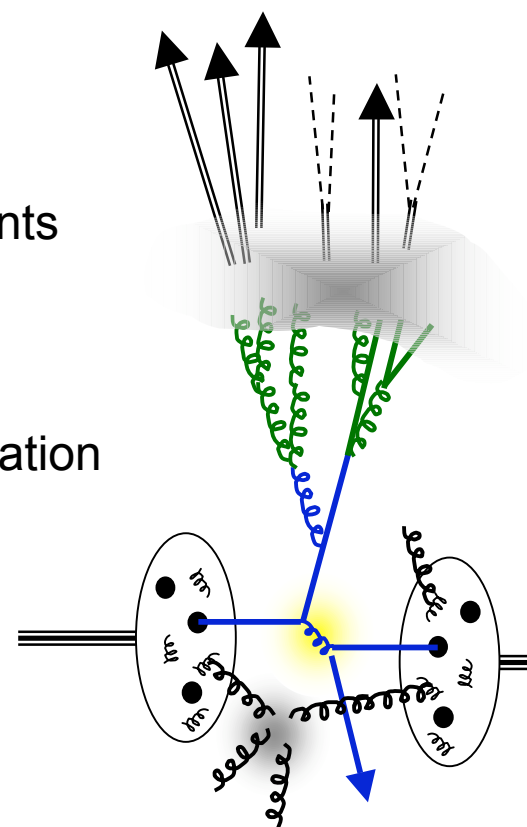
CDF estimate from # reconstructed vertices

Calorimeter jets unfolded to hadron-level jets:

CDF&D0: bin-by-bin unfolding determined from simulation

D0 also uses parameterised functional form

pQCD partons reconstructed into jets for comparison
non-perturbative contributions from underlying event
and fragmentation added.



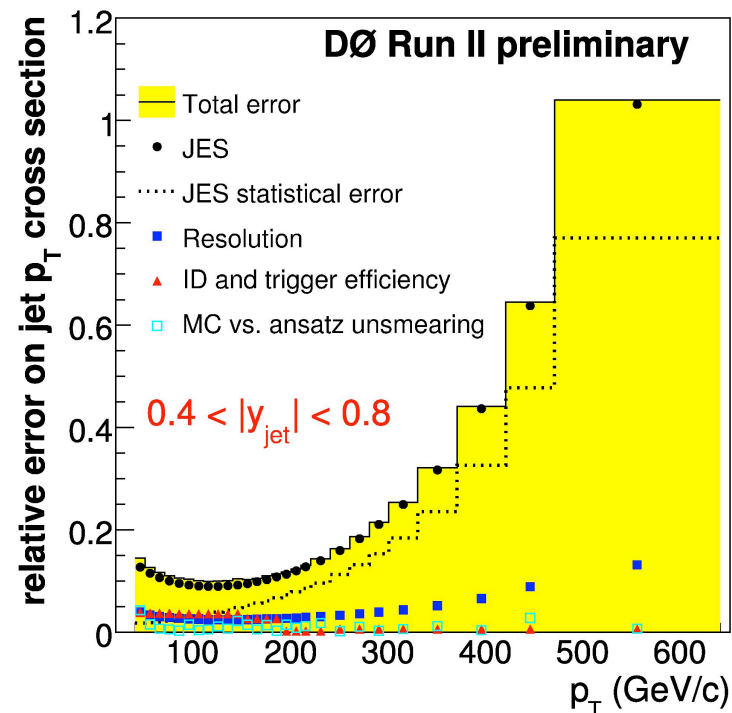
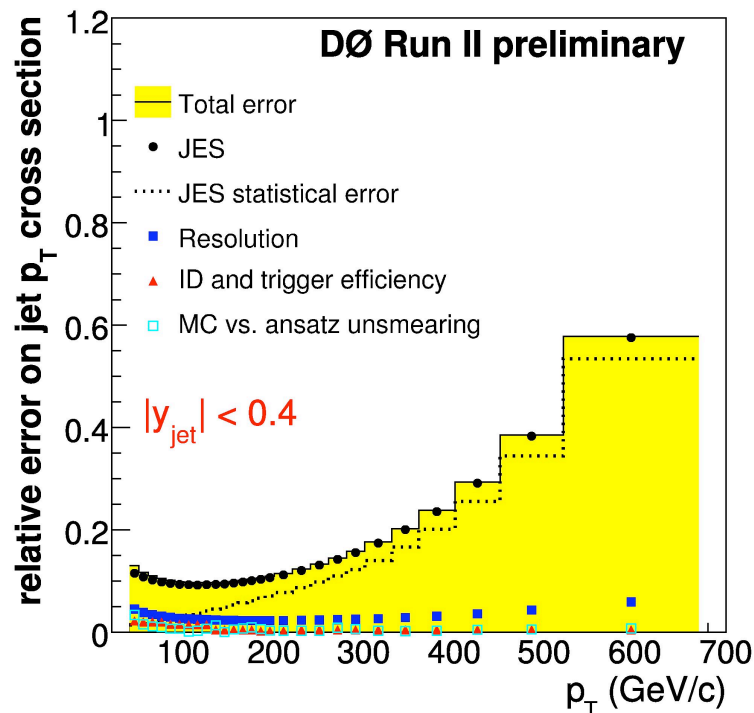
Inclusive Jet Uncertainties

Main uncertainty: jet energy scale

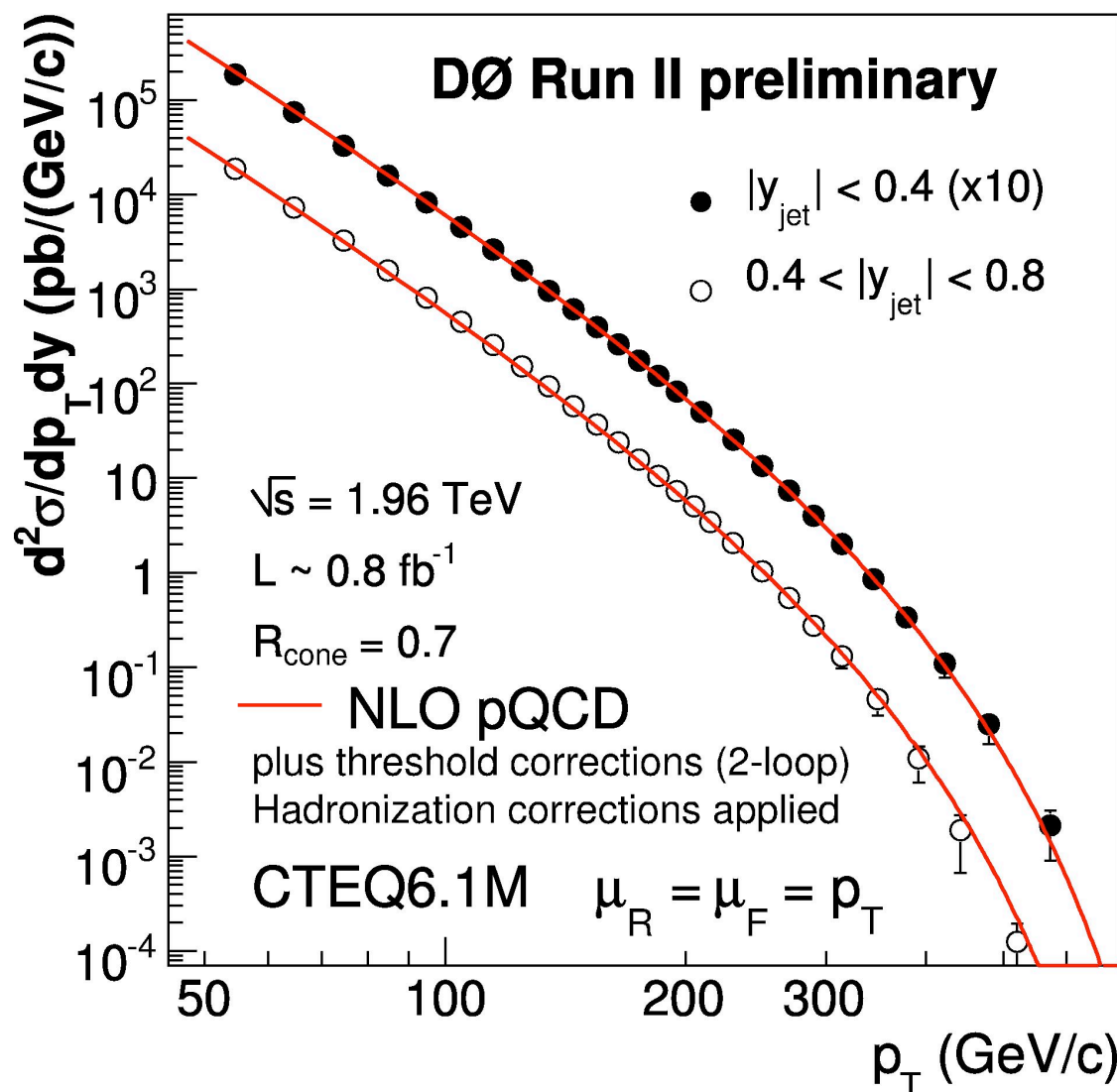
CDF: $\pm 2\text{--}3\%$ JES uncertainty translates to

$\pm 9\%$ cross-section uncertainty at low p_T^{jet} , $^{+60\%}_{-40\%}$ at high p_T^{jet}
also $\pm 8\%$ uncertainty on jet resolution

D0:



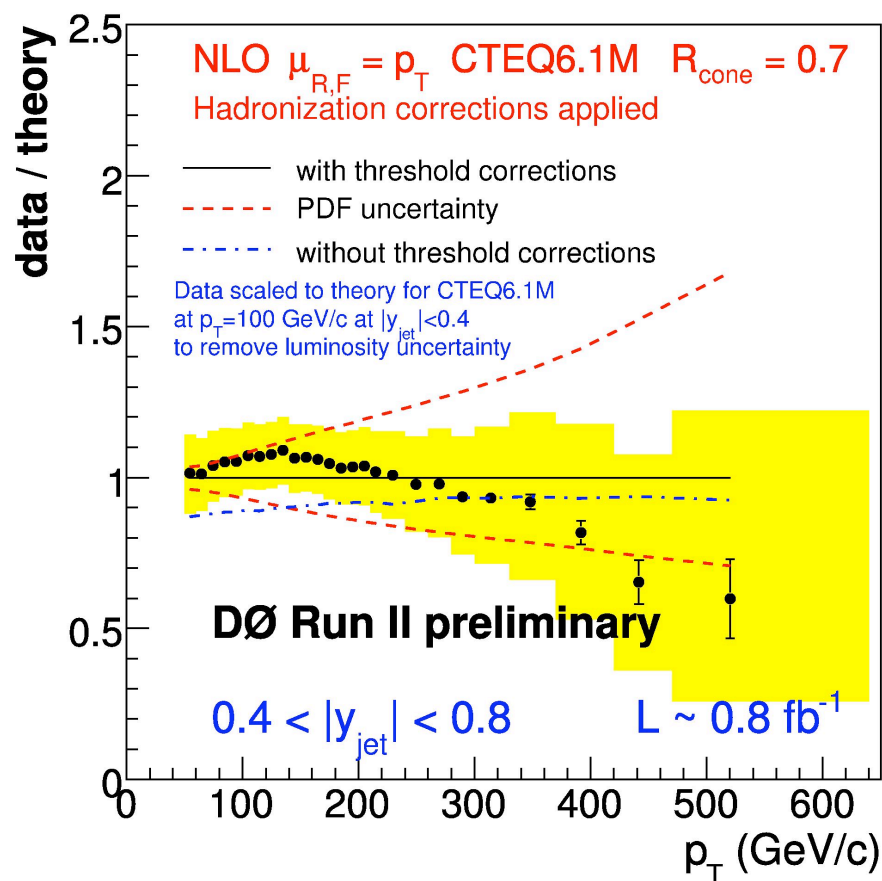
D0 midpoint



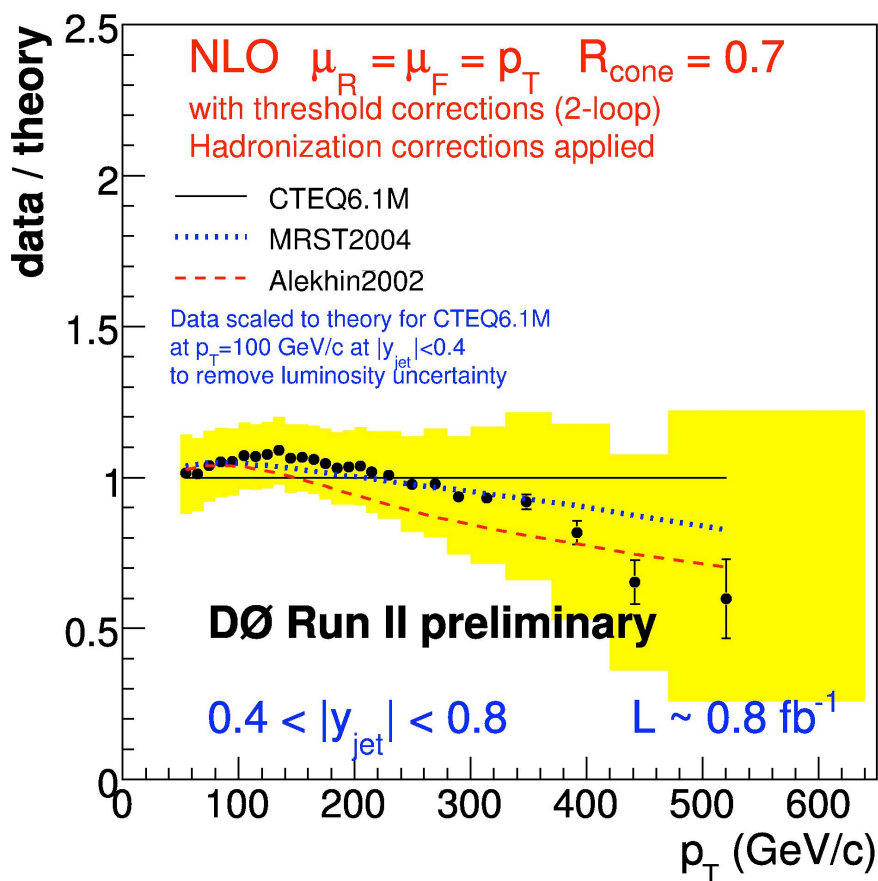
cone 0.7
 $f_{\text{merge}} 0.5$

normalised to
 theory at
 $p_T = 100 \text{ GeV/c}$

D0 midpoint

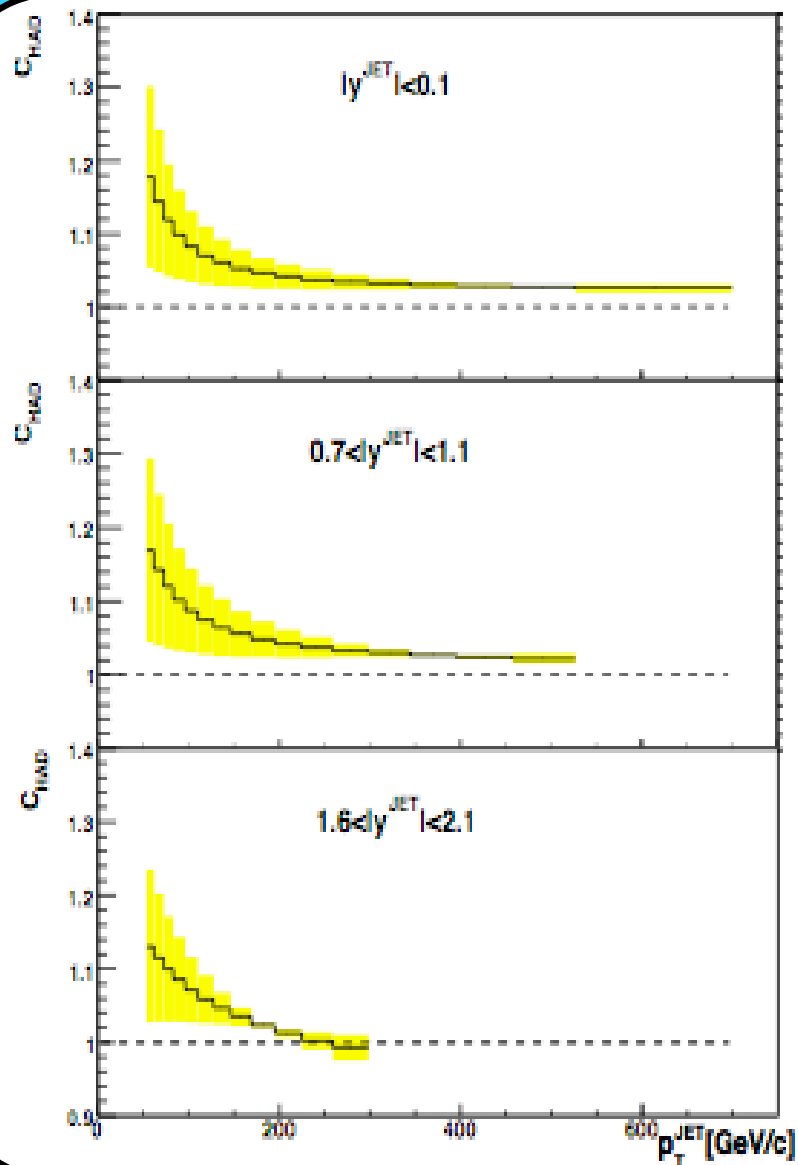


CTEQ Error sets



MRST/CTEQ and Alekhin/CTEQ

CDF k_T



To make comparisons with calculation, include correction for non-perturbative contributions

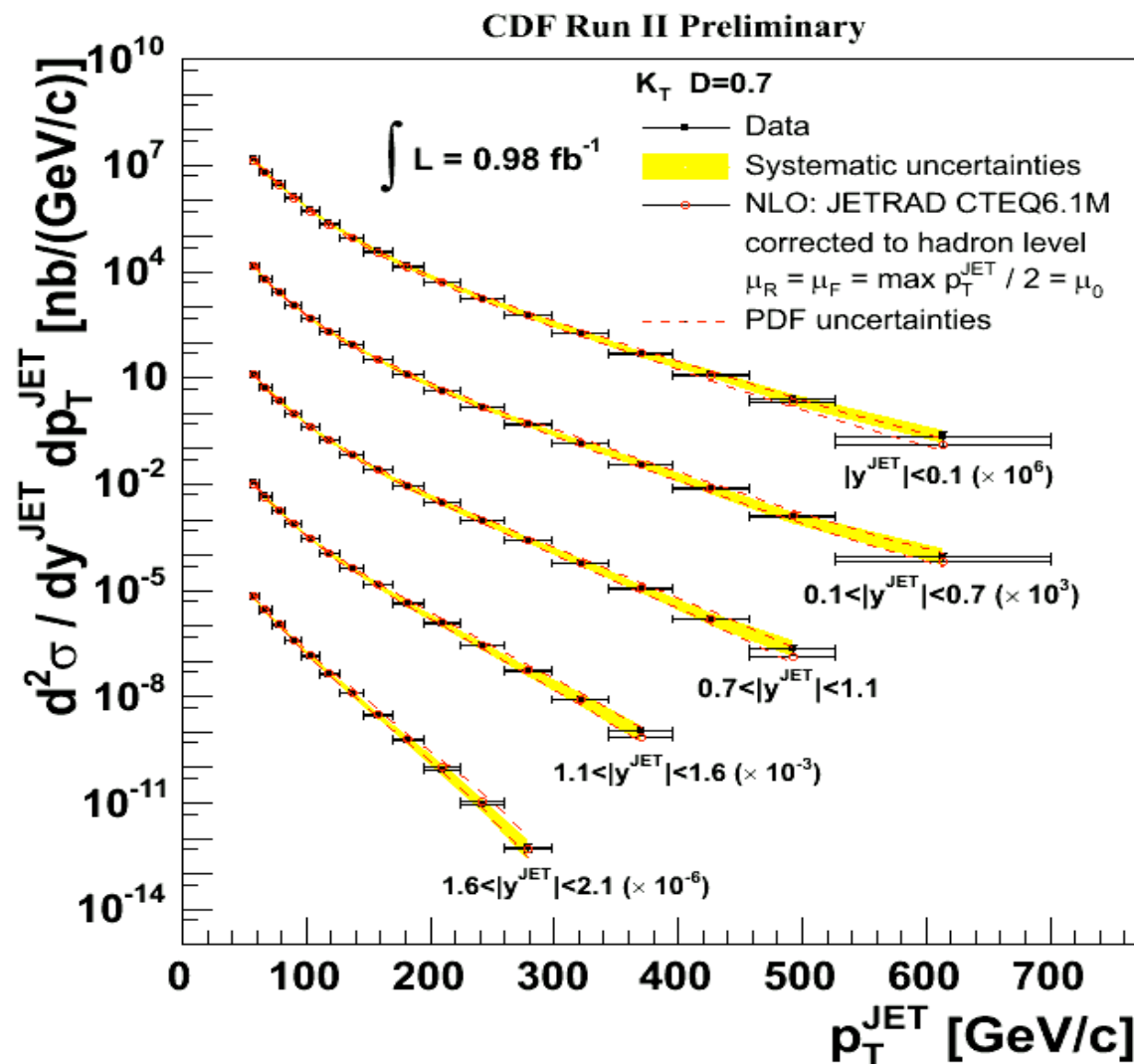
– estimated by turning on/off fragmentation, interactions with beam remnants.

CDF Run II Preliminary

K_T $D=0.7$

— Parton to hadron level correction
 ■ Monte Carlo Modeling Uncertainties

CDF k_T

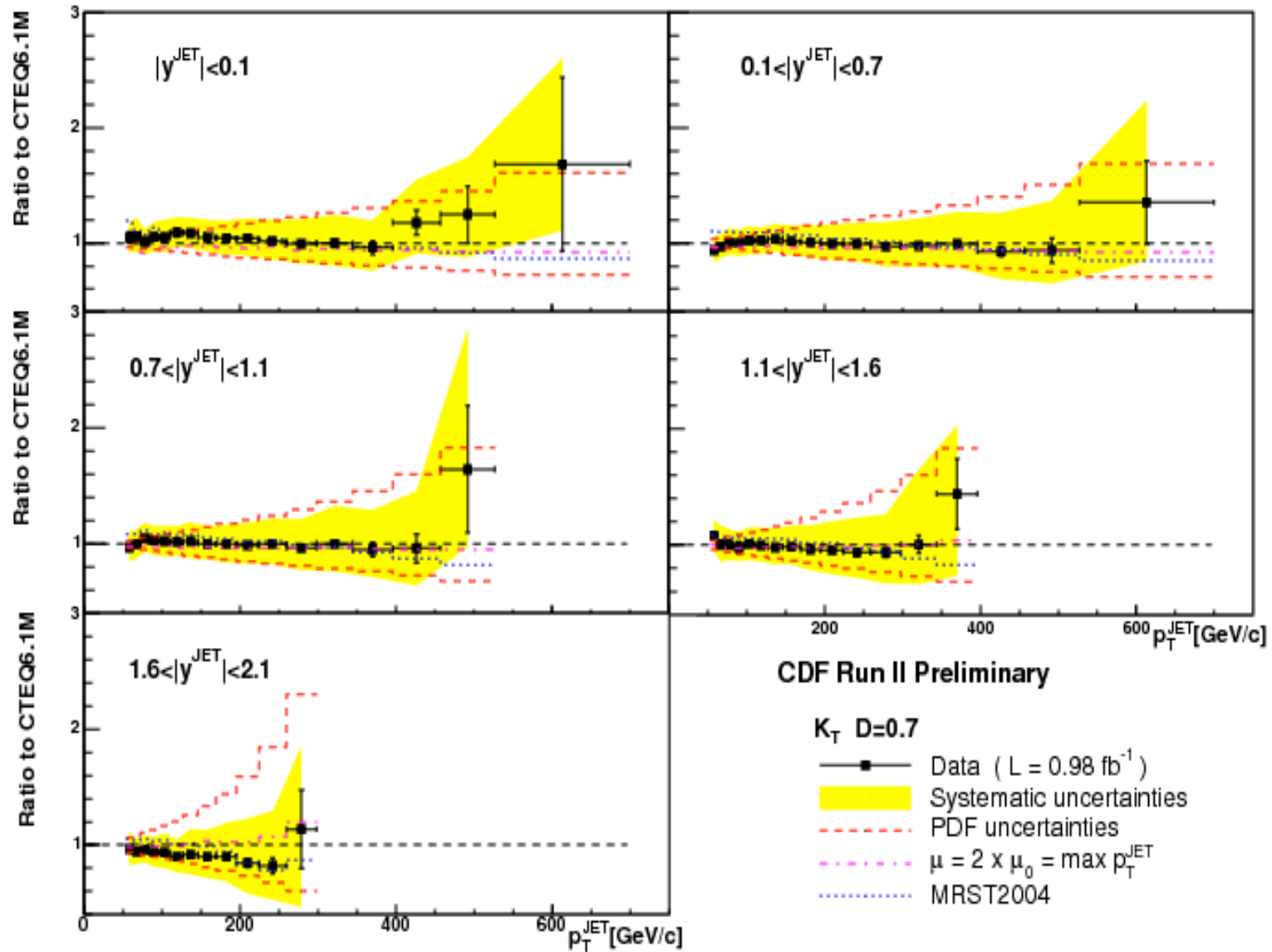


Measured in 5 bins of y^{jet}

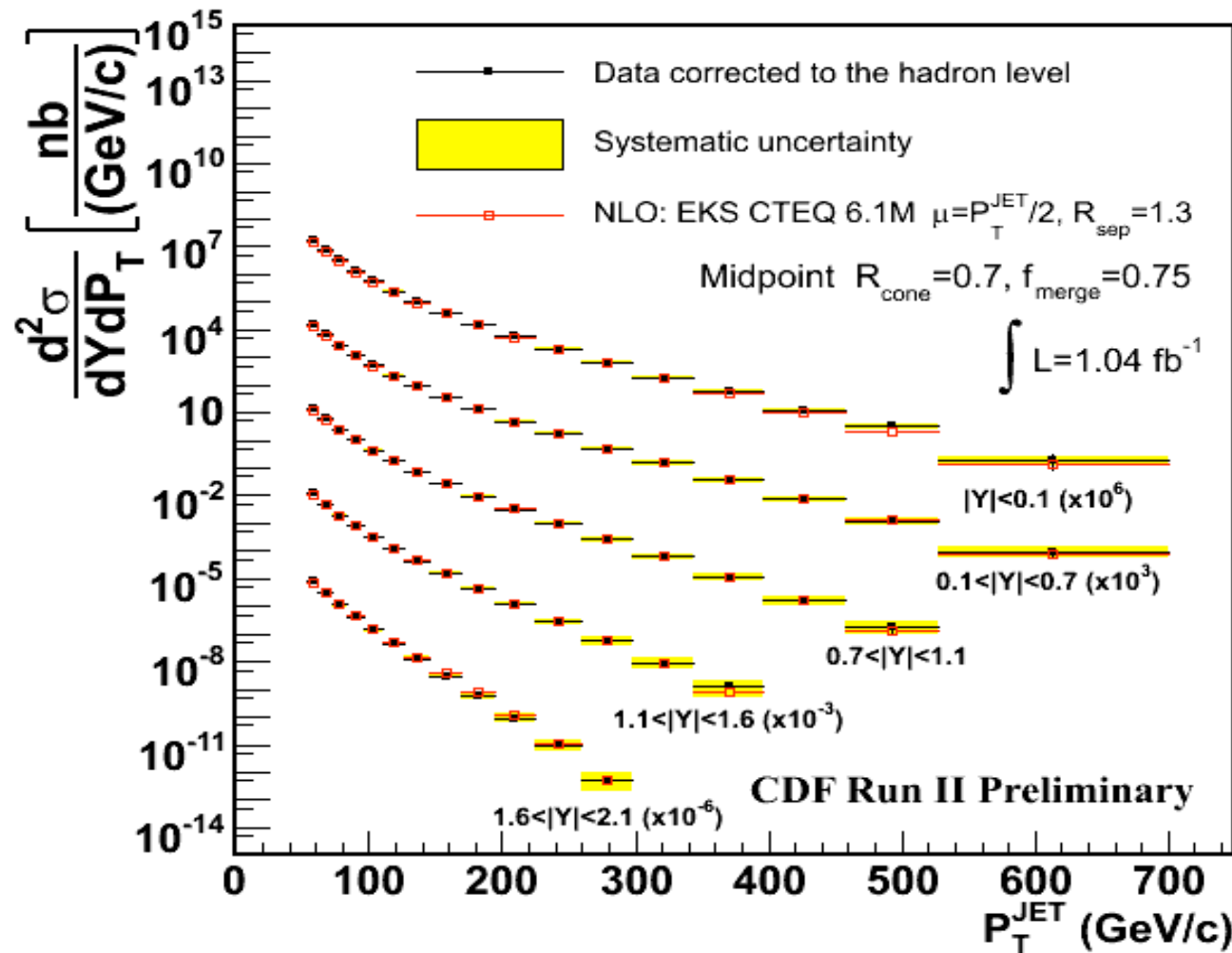
Forward jet \Rightarrow
asymmetric interaction

Don't expect new physics
in high y^{jet} region

CDF k_T

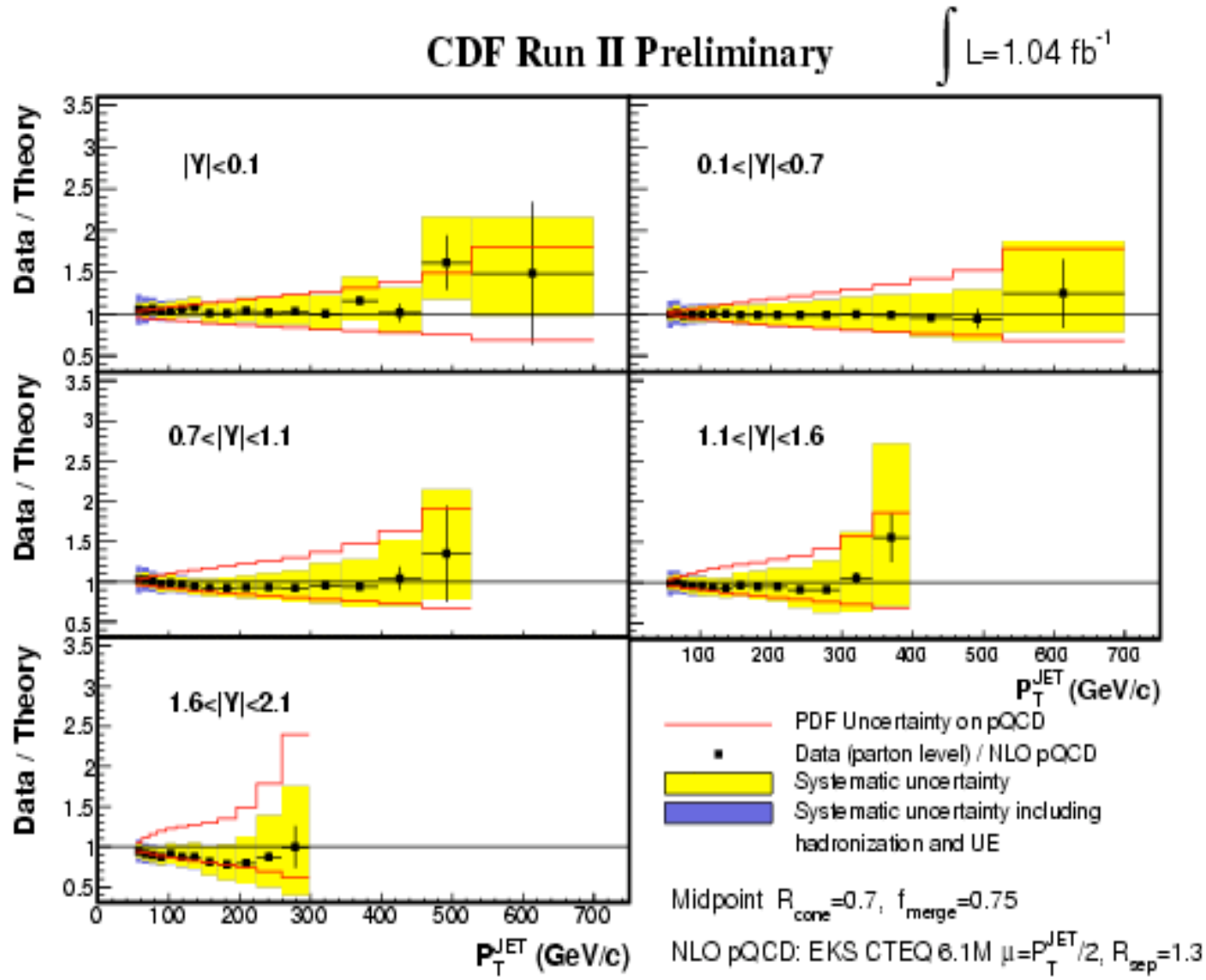


CDF midpoint

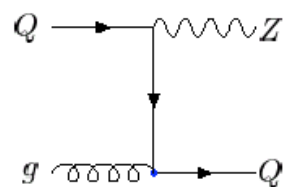
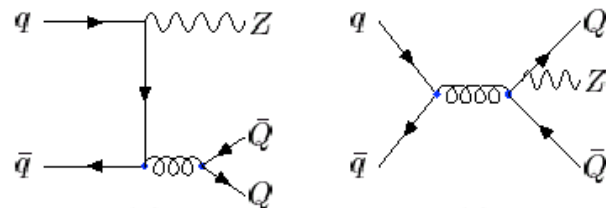


cone 0.7
 $f_{\text{merge}} 0.75$

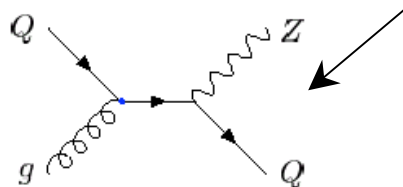
CDF midpoint



Z+b



direct probe of
proton b content
– compare with
radiative generation



$$R = \frac{\sigma(Z+bjet)}{\sigma(Z+jet)}$$

CDF 335/pb	$0.0236 \pm 0.0074_{\text{stat}} \pm 0.0053_{\text{sys}}$
D0 180/pb	$0.021 \pm 0.004_{\text{stat}} \begin{smallmatrix} +0.002 \\ -0.003 \end{smallmatrix}_{\text{sys}}$
NLO calc.	0.018 ± 0.004

Z in association with jets

$$R_{\text{cone}} = 0.7, |\eta^{\text{jet}}| < 1.5, E_T(p_T) > 20 \text{ GeV}$$

b jets “tagged” by displaced vertex
CDF: b fraction extracted from mass
of secondary vertex

D0: charm content assumed from
theoretical prediction $N_c = 1.69 N_b$

$$\sigma(Z/\gamma^*+bjet) \cdot \text{Br}(Z/\gamma^* \rightarrow ee \text{ or } \mu\mu) \\ = (0.93 \pm 0.29_{\text{stat}} \pm 0.21_{\text{sys}}) \text{ pb}$$

CDF 335/pb

NLO: 0.52pb

single top / Higgs background

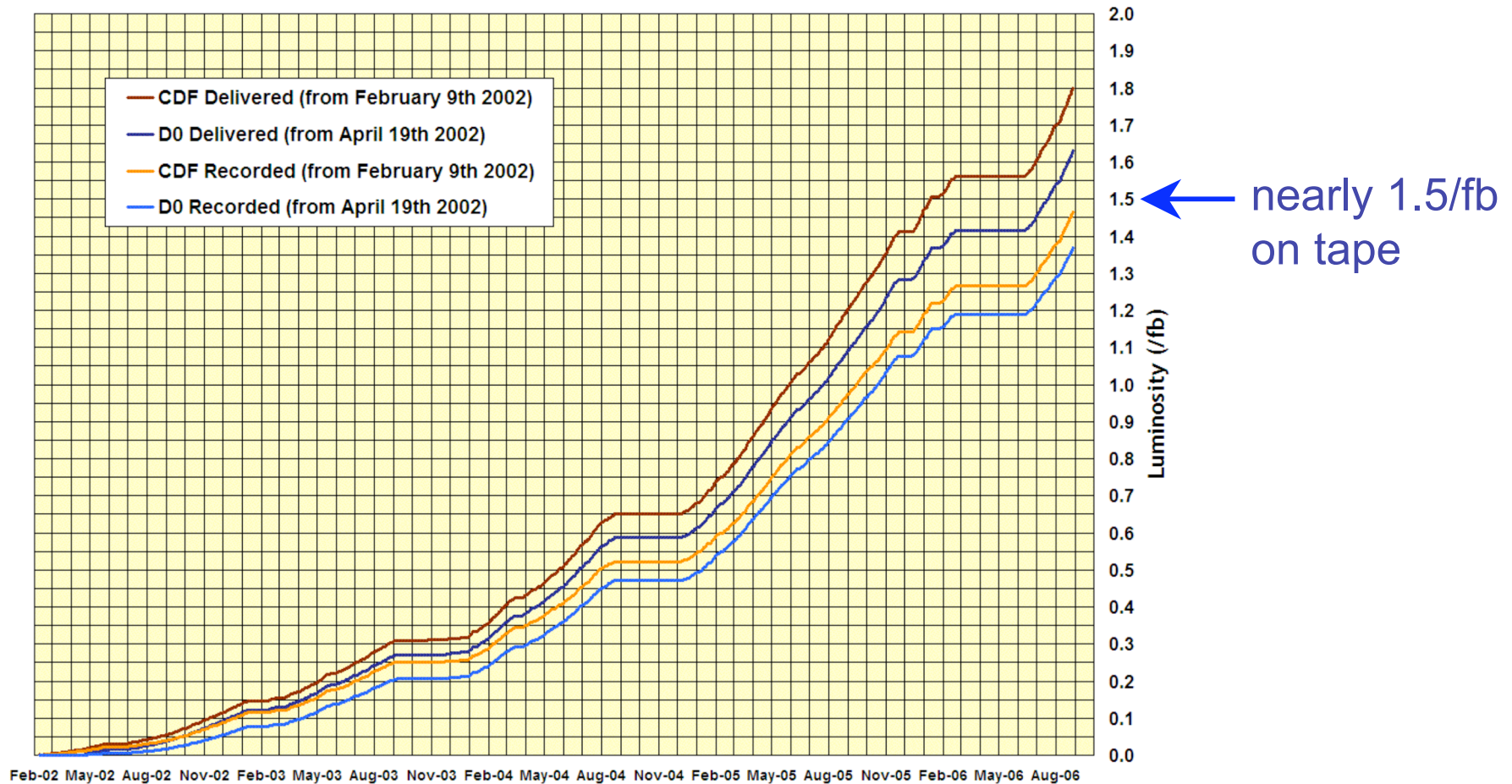
Tevatron performance



D0 & CDF Run II Integrated Luminosity



through 29 August 2006



Summary

As Tevatron datasets increase, PDF uncertainties becoming significant:

- ◆ acceptance calculations
- ◆ theoretical predictions
- ◆ template shapes
- ◆ background estimates
- ◆ ...

Several measurements underway that have good PDF constraining power and are unique to Tevatron:

- ◆ W charge asymmetry for d/u
- ◆ Inclusive jet cross-section for high-x gluon

Other analyses seem promising

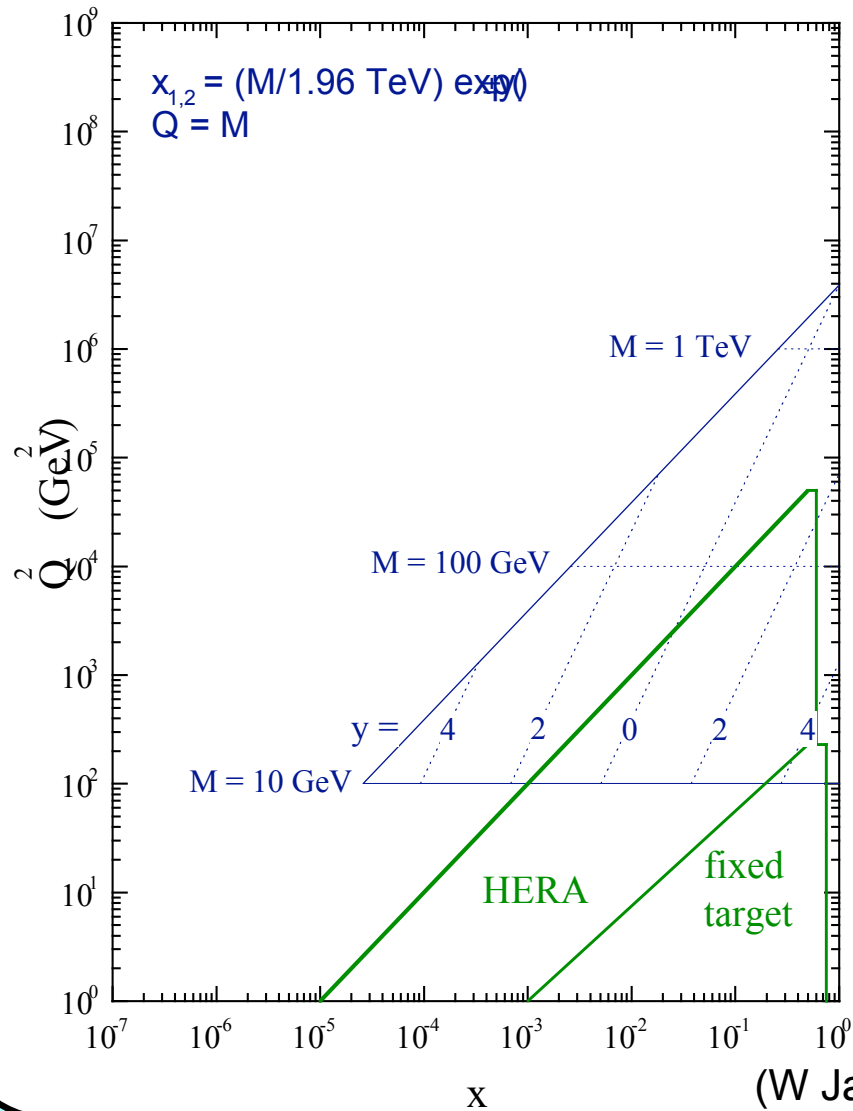
- ◆ Z rapidity
- ◆ Forward W
- ◆ Z+b

key for LHC

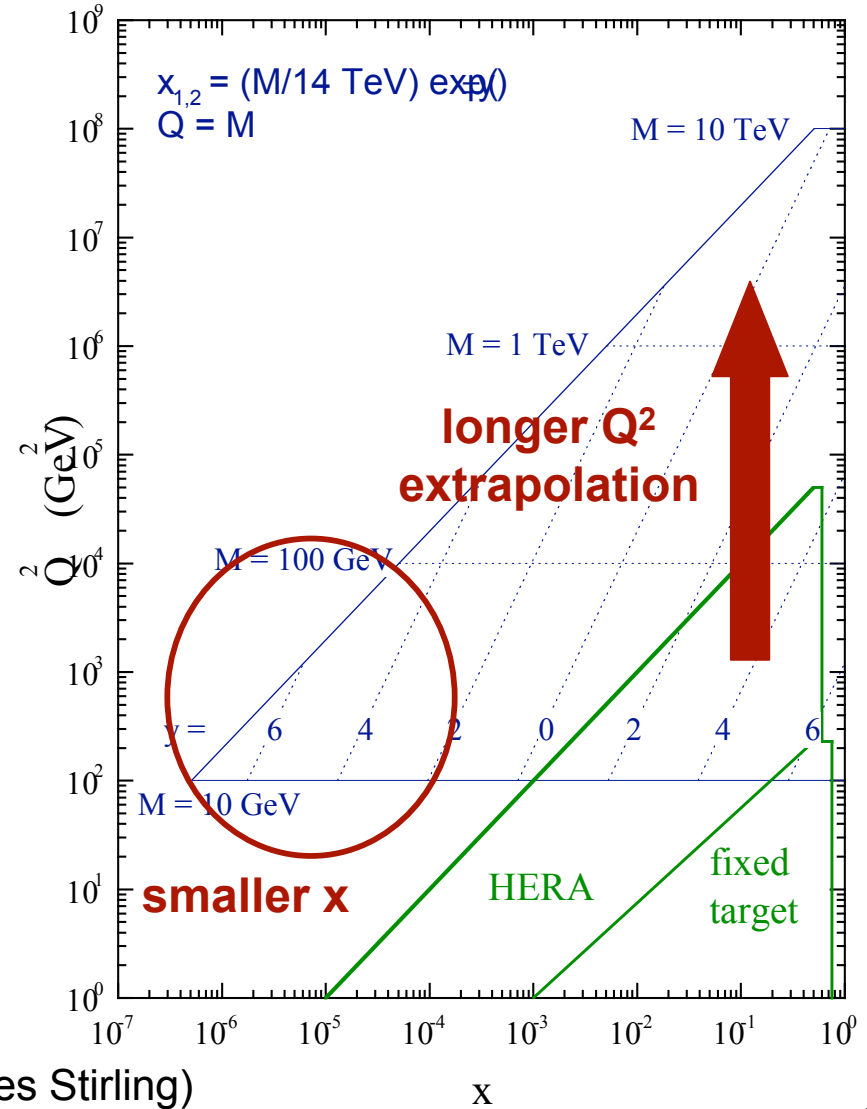


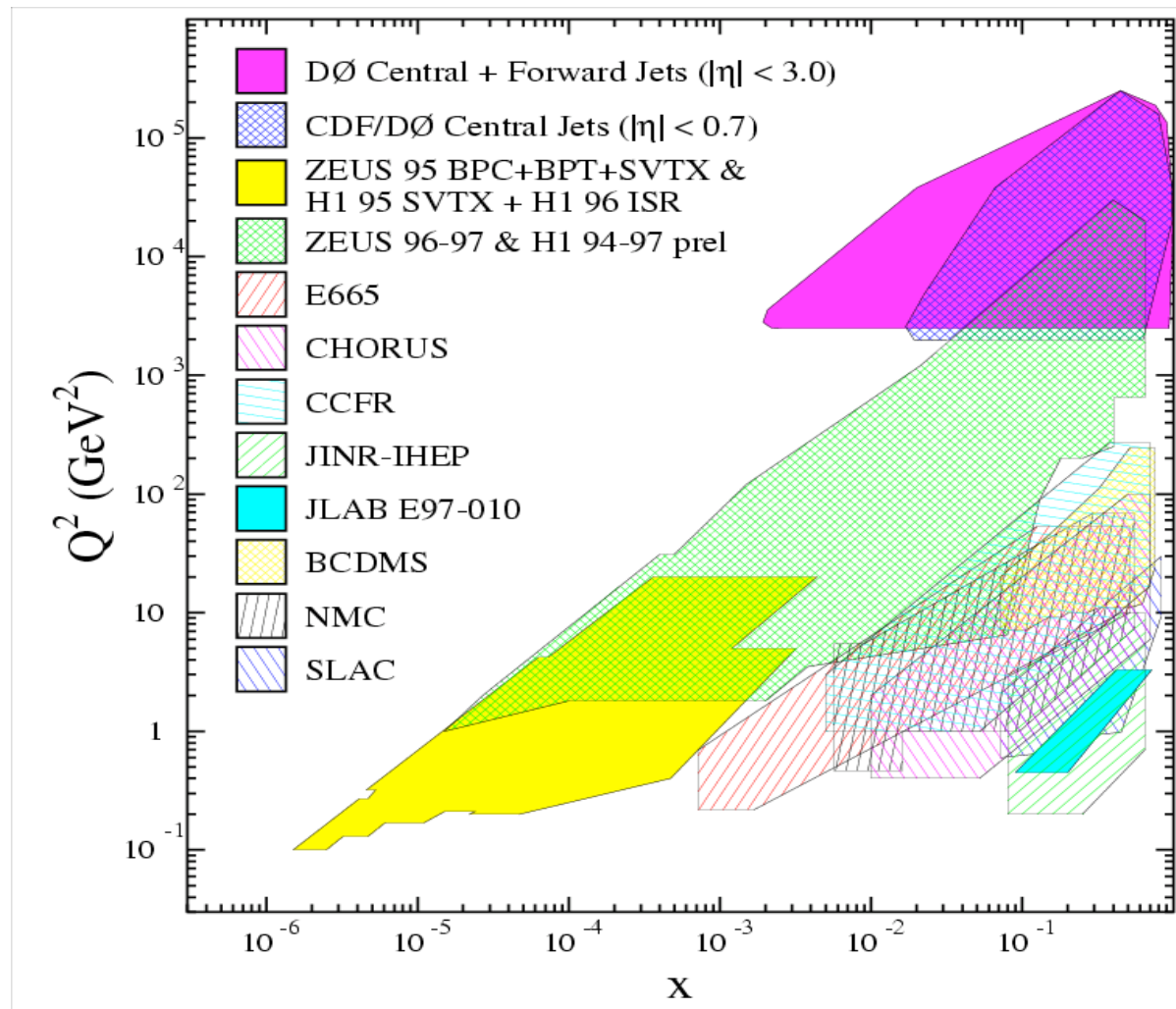
Backup slides

Tevatron parton kinematics



LHC parton kinematics



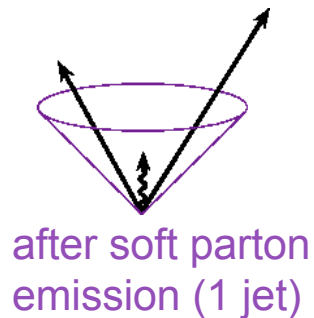
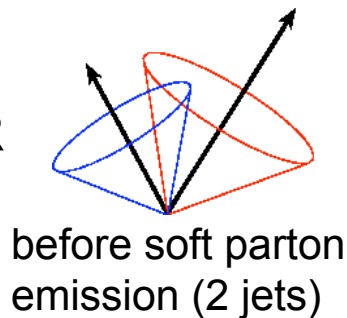


Jet Algorithms

Run 1 cone algorithm

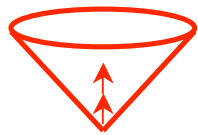
construct cones around seed towers
construct cones around these proto-jets
merge if common $E_T > 75\%$ of smallest jet

**Not IR
safe:**

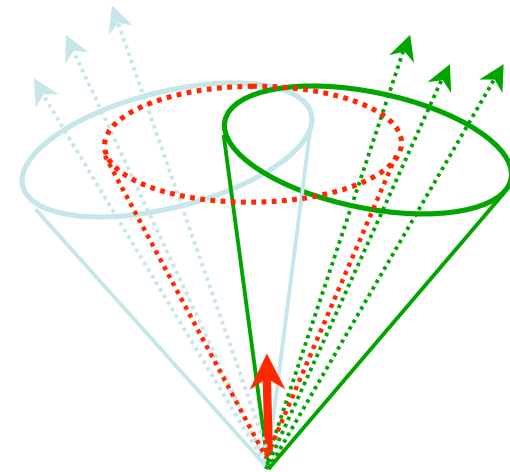


**Not
collinear**

safe: below threshold (no jets) above threshold (1 jet)



Run 2 midpoint algorithm



Put extra seed at midpoint
(η, ϕ) of pairs of proto-jets
separated by less than $2R$.
Iterate.
Merge/split.

Jet Algorithms

Run 2 k_T algorithm

Make an ordered list of $\begin{cases} d_{ij} = \min[(p_T^i)^2, (p_T^j)^2] \frac{\Delta R^2}{D^2} \\ d_i = (p_T^i)^2 \end{cases}$

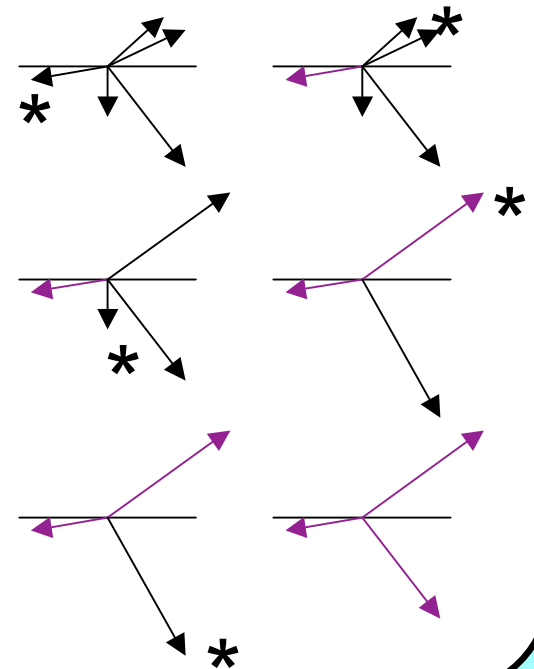
ΔR^2 ← in (η, ϕ) space
 D^2 ← algorithm parameter

Start from smallest $\{d_{ij}, d_i\}$

If it is a d_i it is called a jet and removed from the list

If it is d_{ij} the particles are combined in a “proto jet”

Iterate



D0 midpoint

